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MID-PACIFIC OCEANOGRAPHY
Part V, Transequatorial Waters, May-June 1952, August 1952

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Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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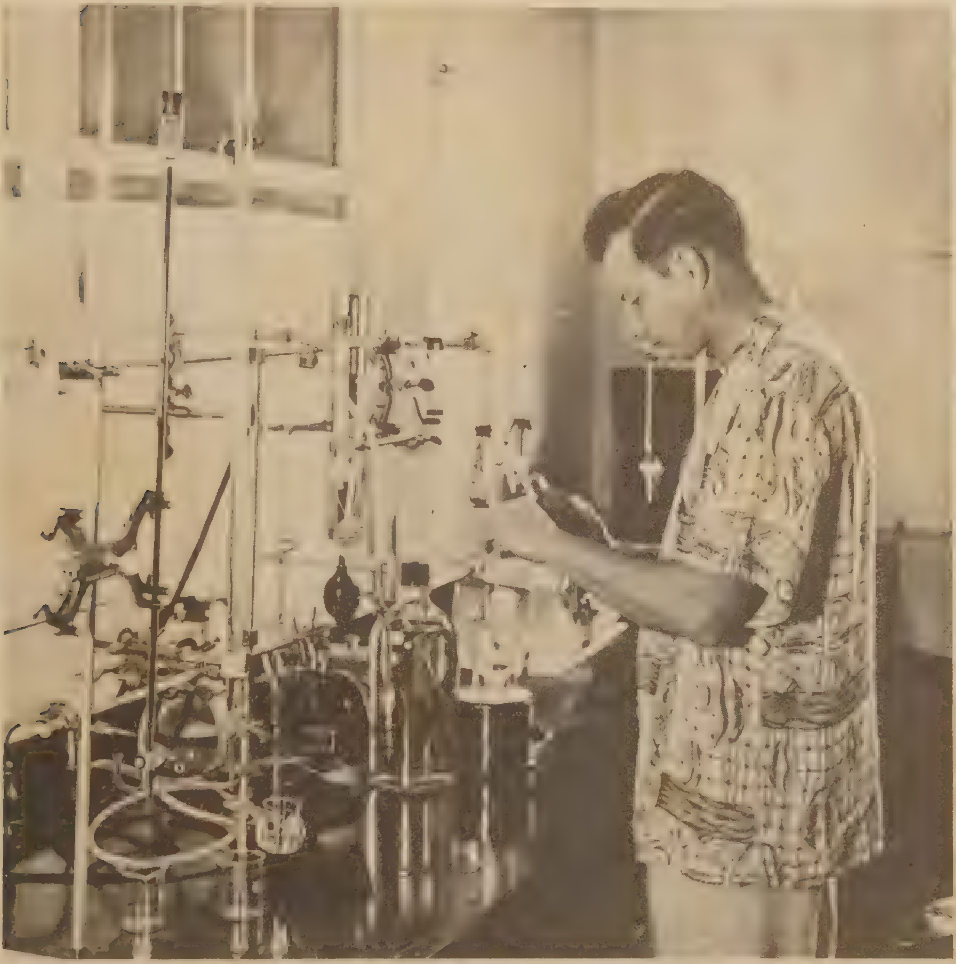

MID-PACIFIC OCEANOGRAPHY PART V
TRANSEQUATORIAL WATERS
MAY-JUNE 1952, AUGUST 1952

By

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Oceanographer
Pacific Oceanic Fishery Investigations
Honolulu, T. H.

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Introduction

The first four reports in this series, Cromwell (1951 and 1954), Austin (1954) and Stroup (1954), discuss the results of cruises which were planned to provide data leading to a general understanding of the physical and chemical oceanographic features in the mid-equatorial Pacific (140°W. to 180th meridian). The present report is principally concerned with cruise 15 of the Hugh M. Smith, a cruise planned so as to provide data relating to the temporal changes along a meridional section across the equatorial circulation. Also included (Appendix I) are the conventional oceanographic data from cruise 16 of the Hugh M. Smith during which a study of the currents was made by means of shallow and deep drags. Preliminary results from this cruise have been reported by Cromwell, Montgomery, and Stroup (1954). A more detailed report is being prepared.

The present report is descriptive. Its primary purpose is to present the data in a form suitable for staff use and for use by other organizations studying the oceanography of the mid-Pacific region. The data are presented in tabular and graphical form, with but brief descriptions of the salient features. More complete analytical reports will follow as sufficient data from POFI oceanographic cruises in the equatorial region are accumulated.

The cruise plan for Hugh M. Smith cruise 15 called for a joint cruise with the Cavalieri, a vessel chartered by POFI to explore the feasibility of commercial longline fishing in the equatorial area. The Hugh M. Smith was to precede the Cavalieri along 140°W. longitude, determine the current boundaries and advise the Cavalieri where to start fishing. However, due to mechanical failure aboard the Cavalieri, she was forced to temporarily abandon the fishing and return to Honolulu for repairs. The Hugh M. Smith continued the program of oceanographic stations as scheduled.

The Smith departed Pearl Harbor, Territory of Hawaii, on May 21, 1952, and returned on July 1, 1952. The vessel completed a total of 60 oceanographic stations comprising four legs along 140°W. longitude between 9°N. and 7°S. latitudes. The station positions for cruise 15 are shown on figure 1. Table 1 summarizes the elapsed time for each of the four legs of the cruise.

Table 1

Station number	Position (140°W. long.)	Date	Elapsed time
1	08°59'N.	May 28	--
17	07°00'S.	June 3	6 days
31	08°00'N.	June 8	5 days
45	07°00'S.	June 14	6 days
60	09°00'N.	June 20	6 days

Each station consisted of a 13-bottle cast to 500 meters. Sea water samples for salinity and phosphate were taken at each depth sampled. Two 900-foot bathythermograph lowerings were made at each station with additional lowerings at 10-mile intervals between stations. Standard, 200-meter, oblique zooplankton hauls were made at each station using a 1-meter, 30xxx silk grit-gauze net. The samples collected by these tows have been processed and the resulting data will be discussed in a forthcoming report.

The vessel and procedures have been described in previous reports, particularly those by Cromwell (1951 and 1954). The method of plotting station data[1] and construction of the vertical sections closely follows that of Montgomery (1954).

Some Results of Hugh M. Smith Cruise 15

Meteorological observations: Routine meteorological observations were recorded during the cruise. Entries were made at each of the 10-mile interval bathythermograph lowerings and at each of the oceanographic stations. The U.S.N. Hydrographic Office Oceanographic Log Sheet B (H.O. Pub. 606c) was used. These data are on file at Pacific Oceanic Fishery Investigations, the Scripps Institution of Oceanography, and at the U. S. Navy Hydrographic Office.

Because the zonal circulation and upwelling are primarily wind activated, the wind data from each leg of the cruise are given in figure 2. The data from which the arrows were drawn are listed in table 2. Unless there was a sudden change in speed or direction within increments of one degree of latitude, the speed and direction were averaged for each 60 miles. In figure 2, the direction, as given by the arrow, is to the nearest 10°; the length is proportional to the speed. The figure at the base of the arrow indicates the number of observations used in obtaining, independently, the average speed and direction.

Temperatures: Vertical temperature sections for the four station lines along 140°W. longitude are shown on figures 3 through 6. These cross sections were constructed from bathythermograph lowerings made at 10-mile intervals. The isotherms are at intervals of 2°F. The depth of penetration is indicated by the small horizontal dash. The surface temperatures, as measured in a sample drawn with a bucket, are shown in the top panel. Thermograph records, giving a continuous trace of the surface temperature for the cruise, are available in POFI files.

Referring further to figures 3 to 6, and reading from north to south (right to left), we see evidence of the Equatorial Countercurrent (downward slope of the isotherms from the northern limit of the section to approximately 4-1/2°N. latitude); the South Equatorial Current (4-1/2°N. to southern limit of the section) and the equatorial divergence and upwelling (doming of the isotherms, centered at or near the Equator). The effect of this upwelling on the temperature of surface waters is evidenced in the surface-temperature curve in the upper panel. No well defined convergence, or front, as seen in some previous sections in this region (Cromwell 1953, 1954), was found.

One striking feature of the temperature sections in this area is the well defined thermocline in the region of the Countercurrent. The role which temperature plays with respect to density in this region is evident when these sections are compared with those for sigma-t, figures 8-11.

Attention is directed to the temperature inversions beneath the Equator on figures 3, 4, and 6. As the isotherms are at 2°F. intervals and the resulting isotherms are drawn for the even temperatures, this inversion is not shown in figure 5. Had the 69° isotherm been shown it would have been evident.

---

[1] The data for the Hugh M. Smith oceanographic cruises have been punched onto IBM cards; the calculations (sigma-t at interpolated depths and Δ_D) performed on the Card Program Calculator and the observed, interpolated, and calculated data, as appropriate, tabulated directly onto the stencils. The procedures for the IBM calculations of these oceanographic data were formulated by the Division of Oceanography, U.S.N. Hydrographic Office, Washington 25, D. C. We wish to acknowledge with appreciation their assistance.

These temperature inversions are a characteristic feature of bathythermograms that we have taken at or very near the Equator. Six temperature-depth traces, taken during cruises along various longitudes and at various times, are shown on figure 7. Similar traces made 10 to 30 miles in a north-south direction from those depicted in figure 7 seldom show evidence of the inversion. During cruise 16 of the *Hugh M. Smith*, salinity samples were taken near the upper and lower depths of one of the inversions. The stable character of this feature, as evidenced from its relationship to the sigma-t surfaces, is shown on figure 7, lower panel.

Table 2.--Average wind direction and speed for observations recorded between latitudes listed in column 1

Position	$\bar{D}$	$\bar{F}$	No. obs.	Position	$\bar{D}$	$\bar{F}$	No. obs.
08°00'N.	047	16	6	06°45'N.	100	10	9
07°00'N.	050	18	9	06°00'N.	120	5	3
06°30'N.	040	15	7	05°00'N.	150	8	9
06°00'N.	080	13	6	04°00'N.	120	9	8
05°00'N.	077	15	6	03°00'N.	120	7	7
04°00'N.	180	8	7	02°00'N.	120	8	7
03°00'N.	180	8	7	01°00'N.	120	9	7
02°00'N.	100	5	5	00°00'	080	12	7
01°00'N.	136	4	7	01°00'S.	100	11	7
00°00'	107	8	7	02°00'S.	130	9	7
01°00'S.	089	9	7	03°00'S.	120	12	4
02°00'S.	114	15	7	04°00'S.	120	13	9
03°00'S.	105	12	7	05°00'S.	110	15	6
04°00'S.	094	14	7	06°00'S.	130	15	7
05°00'S.	098	13	7	07°00'S.	120	15	7
06°00'S.	084	9	7				
07°00'S.	099	4	6	06°00'S.	090	18	5
				05°00'S.	070	15	7
06°30'S.	126	14	3	04°00'S.	080	12	5
06°00'S.	131	6	2	03°30'S.	070	12	5
05°30'S.	128	6	4	03°00'S.	120	12	5
05°00'S.	065	4	2	02°00'S.	110	12	7
04°00'S.	125	6	6	01°00'S.	080	9	5
03°00'S.	045	6	5	00°00'	080	9	9
02°00'S.	051	9	6	01°00'N.	070	11	7
01°00'S.	051	11	7	02°00'N.	100	11	7
00°00'	081	12	8	03°00'N.	120	10	5
01°00'N.	083	12	5	04°00'N.	120	11	9
02°00'N.	112	12	7	05°00'N.	120	10	7
03°00'N.	131	13	7	05°30'N.	120	9	4
04°00'N.	121	12	6	06°00'N.	030	4	4
05°00'N.	130	12	7	06°30'N.	070	6	4
05°10'N.	113	15	3	07°00'N.	040	15	3
06°00'N.	129	6	5	08°00'N.	050	15	6
07°04'N.	073	8	9	09°00'N.	020	11	7
08°00'N.	104	10	7				

Sigma-t: The four sections for sigma-t are shown in figures 8 through 11. These sections, as is the case with the subsequent sections for salinity and phosphate, are arranged in the following order: southbound, stations 1 through 17; northbound, stations 17 through 31; southbound, stations 31 through 45; and northbound, stations 45 through 60. The sigma-t surfaces are drawn at 0.2 gm/l intervals.

In general, the picture may be considered characteristic for the central Pacific equatorial region. Reading from north to south (right to left on each of the four sections), we see the pronounced, relatively shallow density gradient associated with the northern edge of the Countercurrent; the inclined surfaces in the Countercurrent and domed configuration associated with the divergence in the South Equatorial Current at or near the Equator.

The trough at the Equator, first evident in the sigma-t surfaces at 75 to 100 meters below the surface, is similar to that pointed out by Cromwell (1954) as characteristic of this region.

Salinity: The salinity sections for the four legs of the cruise are shown on figures 12 to 15. In their general features, these sections are very similar to those described in previous reports of this series (Cromwell 1951, 1954; Austin 1954) and in the report by Montgomery (1954). The tongue of high salinity water (at 100-150 meters, southern half of sections) and the low salinity surface waters of the Countercurrent are pronounced features and will be subsequently discussed in the section on the temperature-salinity relationships (T-S curves).

Inorganic phosphate: The inorganic phosphate sections for each of the four legs are shown in figures 16 to 19. The values for each observation were obtained by means of the molybdenum method, using the Automatic Servo Operated Photometer (Snodgrass et al. 1953).

We can see that in the first two sections the 0.8 µg at/l isopleth reaches the surface in the region of the equatorial divergence, but is to be found beneath the surface waters in the last two sections. In the region of the northern edge of the Countercurrent there is a well developed "phosphocline" with the values increasing from 0.8 to 2.4 µg at/l in a depth range of 10 to 20 meters.

Attention is called to the trough in the phosphate isopleths at about 100 meters below the surface between 2°N. to 2°S. latitudes. Comparing the first section, figure 16, with the last, figure 19, we see the trough as broadened latitudinally, both to the north and south of the Equator, and the lower limit (2.2 µg at/l) decreased in depth from about 425 meters to 350 meters.

Temperature-salinity relationships (T-S curves): A temperature-salinity curve for each station of cruise 15 is plotted in figure 20. The curves have been grouped according to the latitude of the individual stations, 9°N. to 7°S. Interpolated values were used.

In discussing the T-S curve, Sverdrup, et al. (1942) point out that "By means of this diagram, characteristic features of the temperature-salinity distribution are conveniently represented and anomalies in the distribution are easily recognized." In the case of the cruise under discussion, these curves may serve a twofold purpose; they help to classify the zonal currents crossed on the section along 140°W. longitude, and they suggest the variations with time among the four stations at each latitude. Normally, data for the surface layer (less than 200 meters) are omitted, primarily because of seasonal variations and local modifications. In our case, however, these surface layer data, as well as the data from greater depths, have been included in order to show the variations with both time and latitude.

Figure 21 is a "fan" of T-S curves for the first leg of cruise 15. Selected station curves, have been plotted for latitudes between 9°N. to 7°S. (left to right in the figure).

Reading from north to south, we see that the first three curves may, when compared with those from several other cruises in figure 22, be considered as characteristic for the Equatorial Countercurrent. The surface salinity is relatively low and, with increasing depth down to a level of 50 to 100 meters, the temperature changes very markedly while there is relatively little change in salinity. The effect of this large temperature change on the vertical distribution of density is well demonstrated in figures 8 to 11, where the values for sigma-t increase from about 22.5 g/l to 25.5 g/l within a depth range of 10 to 25 meters. Below 300 meters, the T-S relationship is characteristic of the Equatorial Pacific water (Sverdrup, et al. 1942, p. 707). Although cruise 15 did not include stations in the North Equatorial Current, figure 23, giving the T-S relationship for various longitudes at 19°N., illustrates the markedly different characteristics of the adjacent waters to the north of the Countercurrent.

The relatively low surface salinities in the more northerly station of cruise 15 (5°N. to 9°N.) reflect the high annual total precipitation in this region. Jacobs (1951, figure 41, p. 82) shows that the annual total precipitation over the Pacific Ocean, 55°N. to 55°S., averaged for each 10° of latitude, reaches a maximum between the Equator and 10°N.

For comparative purposes, a summary of the rainfall in the Line Islands, somewhat to the west of the 140th meridian, is given in figure 24. The monthly mean rainfall is given for four of the northern Line Islands (Palmyra, Washington, Fanning, and Christmas), for Malden Island in the southern Line Islands, and for Canton Island in the Phoenix group. The position of each of these islands and the number of years of observations used for determining the means are given in table 3 below.

Table 3

Island[1]	Latitude	Longitude	Years
Palmyra[1]	5°38'N.	162°05'W.	2
Washington[2]	4°50'N.	160°30'W.	3-5
Fanning	3°52'N.	159°23'W.	33-37
Christmas	2°00'N.	157°15'W.	4-7
Malden	4°01'S.	155°01'W.	36
Canton[3]	2°46'S.	171°43'W.	7

[1] The data for Palmyra Island were from unpublished records provided by the U. S. Weather Bureau.

[2] The data for Washington, Fanning, Christmas, and Malden Islands were taken from an unpublished report prepared by C. E. Palmer (1953).

[3] The data for Canton Island were from published records of the U. S. Weather Bureau (1954).

Returning to Jacob's paper, his figures 43 and 44, page 85, show that on 140°W., between the Equator and 10°N., precipitation exceeds evaporation during the spring (March-May) and the summer (June-August). Hugh M. Smith cruise 15, May 28 to June 20, 1952, bridges his classification for the two seasons. Our data for the years 1950-1953, and between 140°W. and 180th meridian, indicate that the latitudinal position for salinity minimum and the maximum excess of precipitation over evaporation lies between 5° and 10°N. latitudes, rather than centered on 5°N. latitude (see Jacob's figure 51 D, p. 95). However, the effect of the horizontal flow (Equatorial Countercurrent and South Equatorial Current) on the surface salinity is yet to be studied. These zonal currents may, and undoubtedly do, displace the areas of maximum (or minimum) salinity in the direction of the surface flow and away from areas of maximum or minimum precipitation.

Proceeding to the two southernmost stations (5°30'S. and 7°S.) in figure 21, the T-S curves are characterized by the salinity maximum above 200 meters. This maximum is present at these latitudes on all longitudes we have sampled, i.e., 140°W. to the 180th meridian (figure 25). That this high salinity with its origin from the subtropical convergence is continuous to the west of the 180th meridian can be seen from figure 30(b) of Mao and Yoshida (1953).

One particularly outstanding feature of figures 20 and 21, is the rather sudden transition in the T-S relationship between 1°N. latitude and the Equator. This suggests that the layer of salinity maximum is eradicated very near the Equator by processes associated with the equatorial divergence and upwelling.

Several similar stations within 1° north or south of the Equator and at various longitudes are shown in figure 26. The method of selecting the stations included in this figure was to choose the station, along the particular meridian, with the lowest surface temperature. Thus, their positions were near the center of the equatorial divergence. It is interesting to note that two of the stations thus selected (Hugh M. Smith cruise 15, station 11 and Hugh M. Smith cruise 16, station 18) show evidence of extension of the tongue of high salinity from the south; two are intermediate (Hugh M. Smith cruise 5, station 22 and Hugh M. Smith cruise 14, station 24) and the fifth station, number 34 for Hugh M. Smith cruise 5, suggests that processes associated with the divergence have limited the northward extent of the high salinity tongue.

Figure 27 serves as a summary of the T-S relationships discussed above. An average curve for the stations at 19°N., 7°N., the Equator, and 7°S. are shown. The T-S curves for the Equatorial Pacific and the Western North Pacific Central waters, as taken from figure 209 B, page 741 of The Oceans (Sverdrup, et al. 1942) have been included as broken lines.

Discussion

Thus far, this report has been concerned primarily with presenting the data from each of the legs of cruise 15 of the Hugh M. Smith and describing some of the more prominent features revealed by these data. Figures 28 to 31 were prepared to describe some of the temporal changes. For each field, temperature (figure 28), salinity (figure 29), sigma-t (figure 30) and phosphate-phosphorus (figure 31), selected isopleths have been plotted for the first and fourth legs of the cruise (stations 1-17 and 45-60).

In the upper panel of figure 28, we have plotted the surface temperatures as read from the bucket thermometer at each bathythermograph lowering (solid line, stations 1-17; broken line, stations 45-60). In the lower panel, the 60°, 70°, and 80° F. isotherms, for the two sections, are plotted against depth as smoothed curves. These isotherms were originally plotted in figures 3 and 6. At least four features are of interest:

1. The slope of the isotherms associated with the Countercurrent is greater in the fourth than in the first leg, suggesting an increased easterly flow of the Countercurrent.

2. The 80° isotherm - surface intercepts for the fourth section have moved to the north and south of those for the first section. This change is reflected in the surface temperatures (upper panel).

3. The 70° isotherm, lying below the surface at the Equator, shows considerably more "doming" in the fourth section.

4. The trough in the 60° and 70° isotherms, centered under the Equator in the first section, has shifted to the south in the fourth.

The salinity section, figure 29, shows considerable variation. There is a generally southerly shift in the selected isohalines when the two sections are compared. Also, the 34.8 °/oo isohaline was extended to the north through the region of the Countercurrent; the northerly tongue of 35.0 °/oo water, 3°N., between 50 and 100 feet, has essentially disappeared and the tongue of high salinity water from the south (35.6 °/oo, 7°N. to 1°S.) has broken into two segments.

A comparable figure for sigma-t, figure 30, shows a similar change in the slope of the isopleths in the region of the Countercurrent. In addition, the relative geographical positions for the selected sigma-t surfaces show a general displacement to the south when comparing the first and fourth sections.

The most apparent changes in the phosphate sections (fig. 31) are the deepening of the 0.8 and 2.0 µg at/l isopleths in the region of the Countercurrent (associated with the suggested change in flow mentioned in discussion of the temperature sections) and the change in configuration of the 0.8 µg at/l isopleth near to and south of the Equator.

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The successful completion of the sea-going oceanographic research program was dependent, in part, on the cooperation and efforts of the Captain and crew of the vessel.

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23. T-S curves, 19°N. latitude, various longitudes, 157°W. to 171°W.
24. Average monthly and annual rainfall for Palmyra, Washington, Fanning, Christmas, Malden, and Canton islands.
25. T-S curves, 7°S. latitude, various longitudes, 140°W. - 180th meridian.
26. T-S curves, Equator, various longitudes, 140°W. - 180th meridian.
27. Average T-S curves, 19°N., 7°N., Equator, and 7°S.
28. Comparison, 60°, 70°, and 80° isotherms, stations 1-17 with stations 45-60.
29. Comparison, various isohalines, stations 1-17 with stations 45-60.
30. Comparison, various sigma-t surfaces, stations 1-17 with stations 45-60.
31. Comparison, 0.8 µg at/l and 2.0 µg at/l phosphate isopleths, stations 1-17 with stations 45-60.

No. 1, Appendix A. Station positions, Hugh M. Smith cruise 16, July 23 - August 29, 1952.

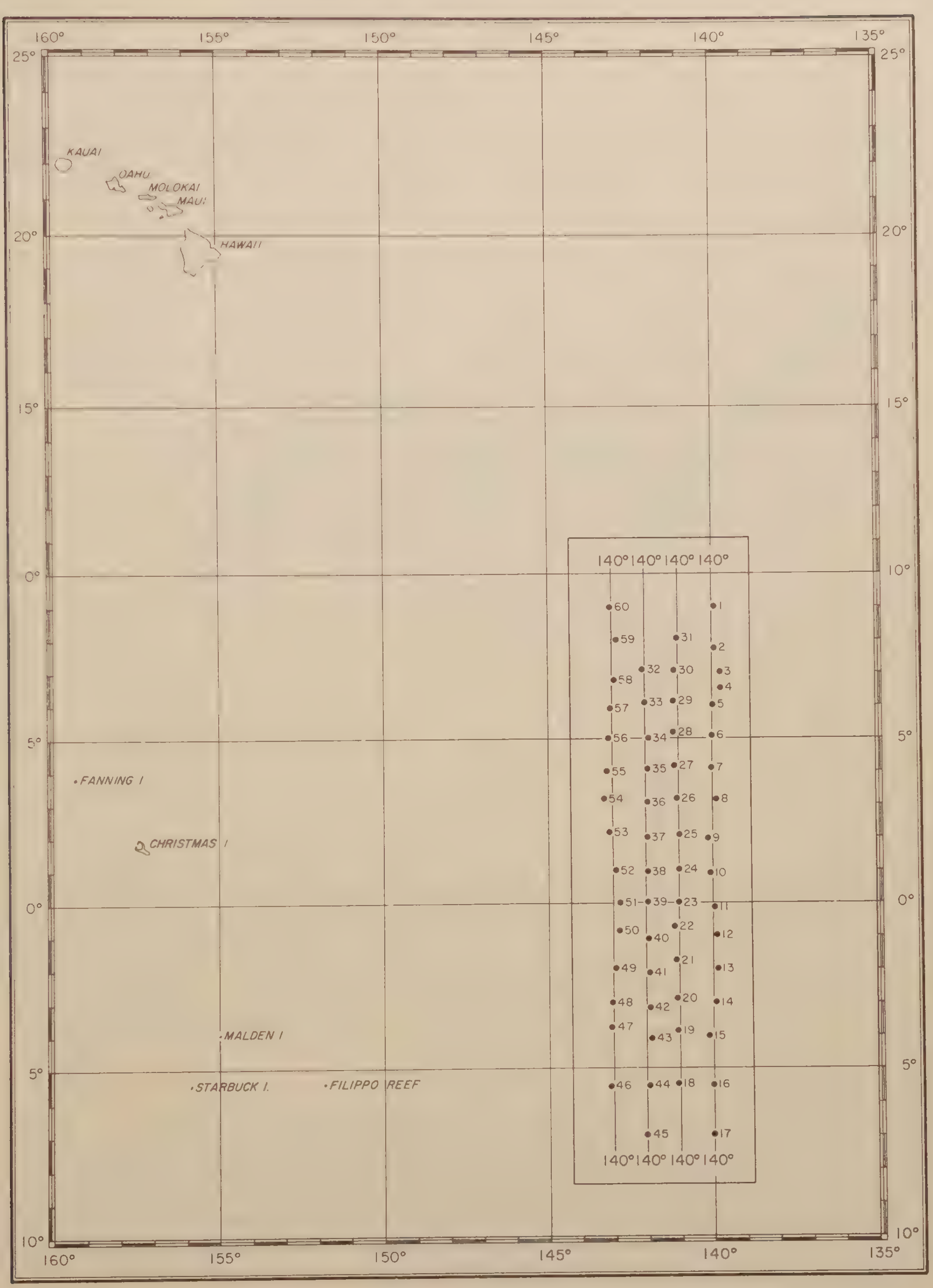
160°
155°
150°
145°
140°
135°
25°
20°
15°
10°
5°
0°
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
FANNING I
CHRISTMAS I
MALDEN I
STARBUCK I.
FILIPPO REEF
140° 140° 140° 140°
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Fig. 1. -- Station positions for Hugh M. Smith cruise 15, stations 1-60, May 28 - June 20, 1952.

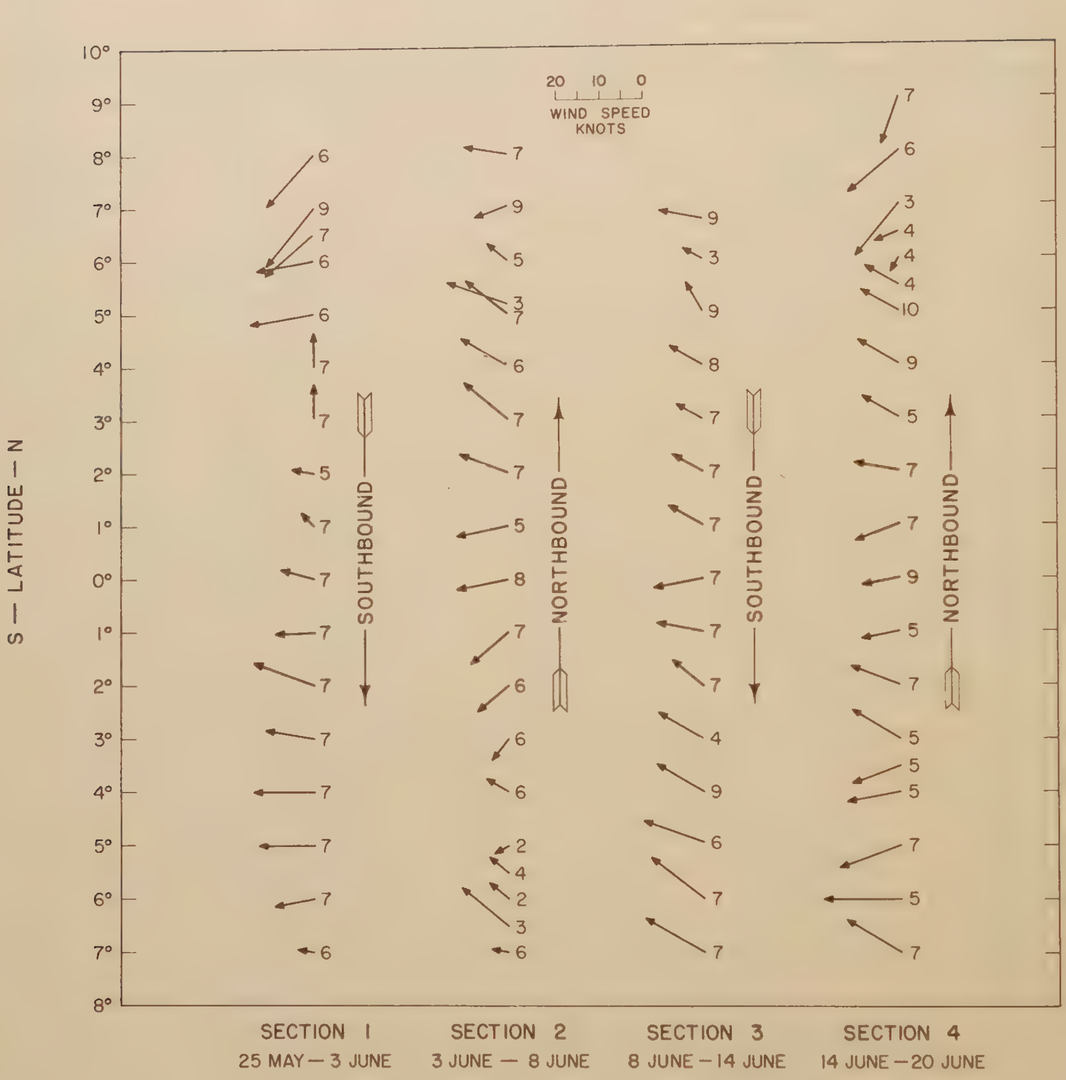


Fig. 2. -- Wind speed and direction. 140°W. longitude, May 28 - June 20, 1952. Each arrow denotes the average speed and the direction of the wind for all observations recorded in the interval of latitude from the position of the previous arrow. The figure at the base of the arrow is the number of observations included in each average.

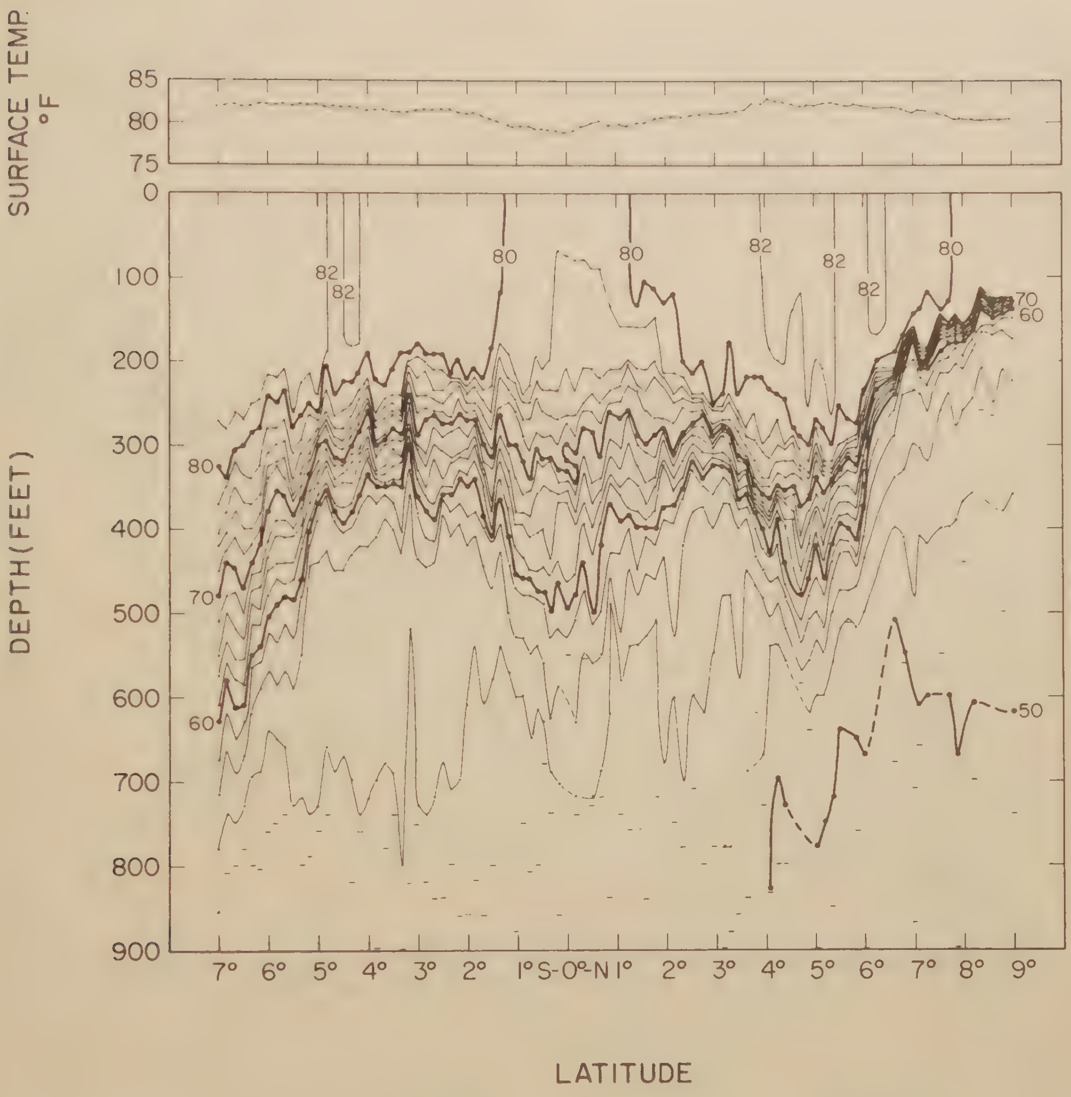


Fig. 3. -- Surface temperatures and vertical temperature section. Southbound, stations 1-17, May 28.- June 3, 1952. Upper panel. Surface temperatures as read at each bathythermograph lowering. Lower panel. Temperature section based on bathythermograph lowerings, isotherms at 2°F. interval, depth of lowering shown by small, horizontal dashed line.

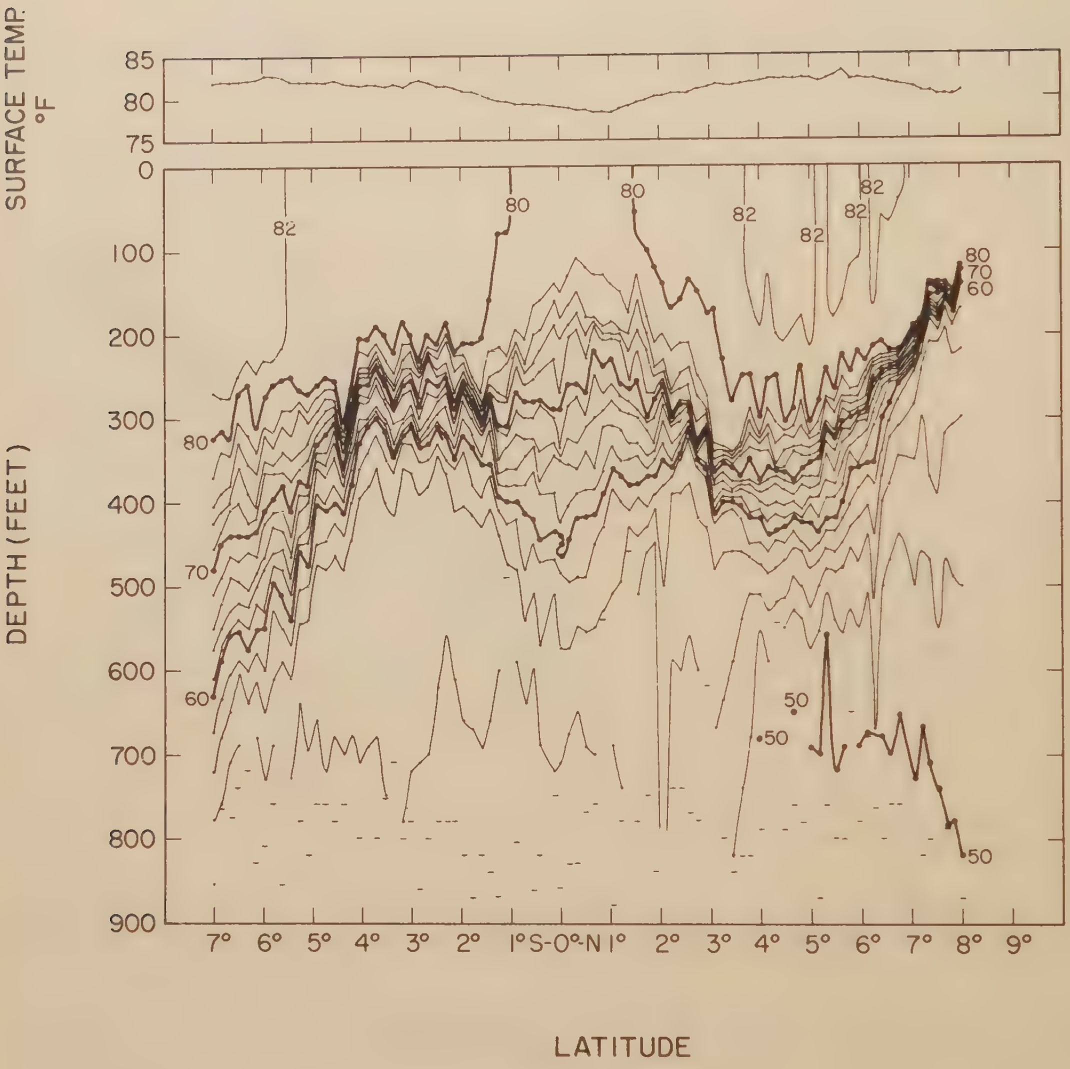


Fig. 4. --Surface temperatures and vertical temperature section. Northbound, stations 17-31, June 3-8, 1952. Upper panel. Surface temperatures as read at each bathythermograph lowering. Lower panel. Temperature section based on bathythermograph lowerings, isotherms at 2°F. interval, depth of lowering shown by small, horizontal dashed line.

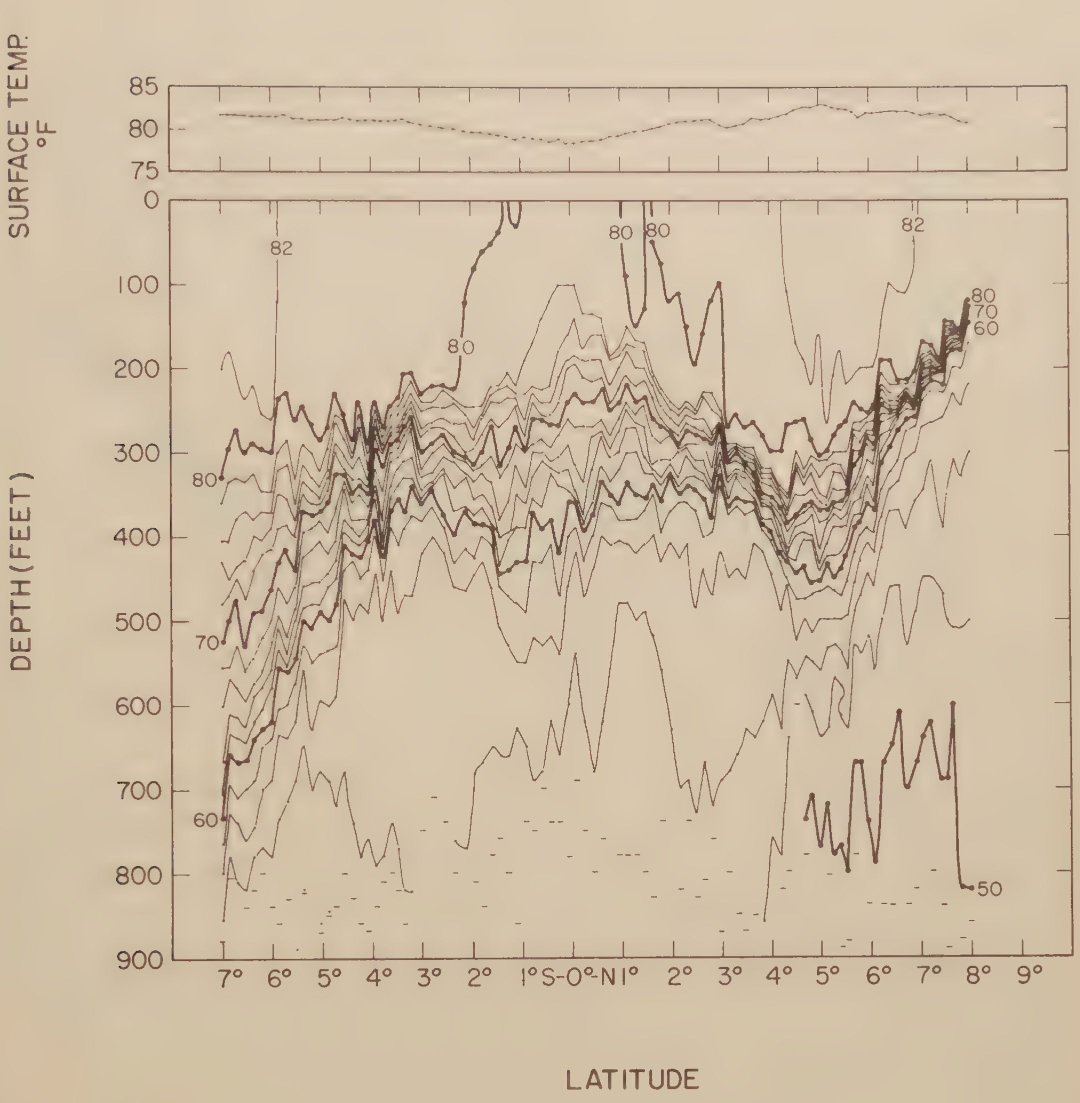


Fig. 5. --Surface temperatures and vertical temperature section. Southbound, stations 31-45, June 8-14, 1952. Upper panel. Surface temperatures as read at each bathythermograph lowering. Lower panel. Temperature section based on bathythermograph lowerings, isotherms at 2°F. interval, depth of lowering shown by small, horizontal dashed line.

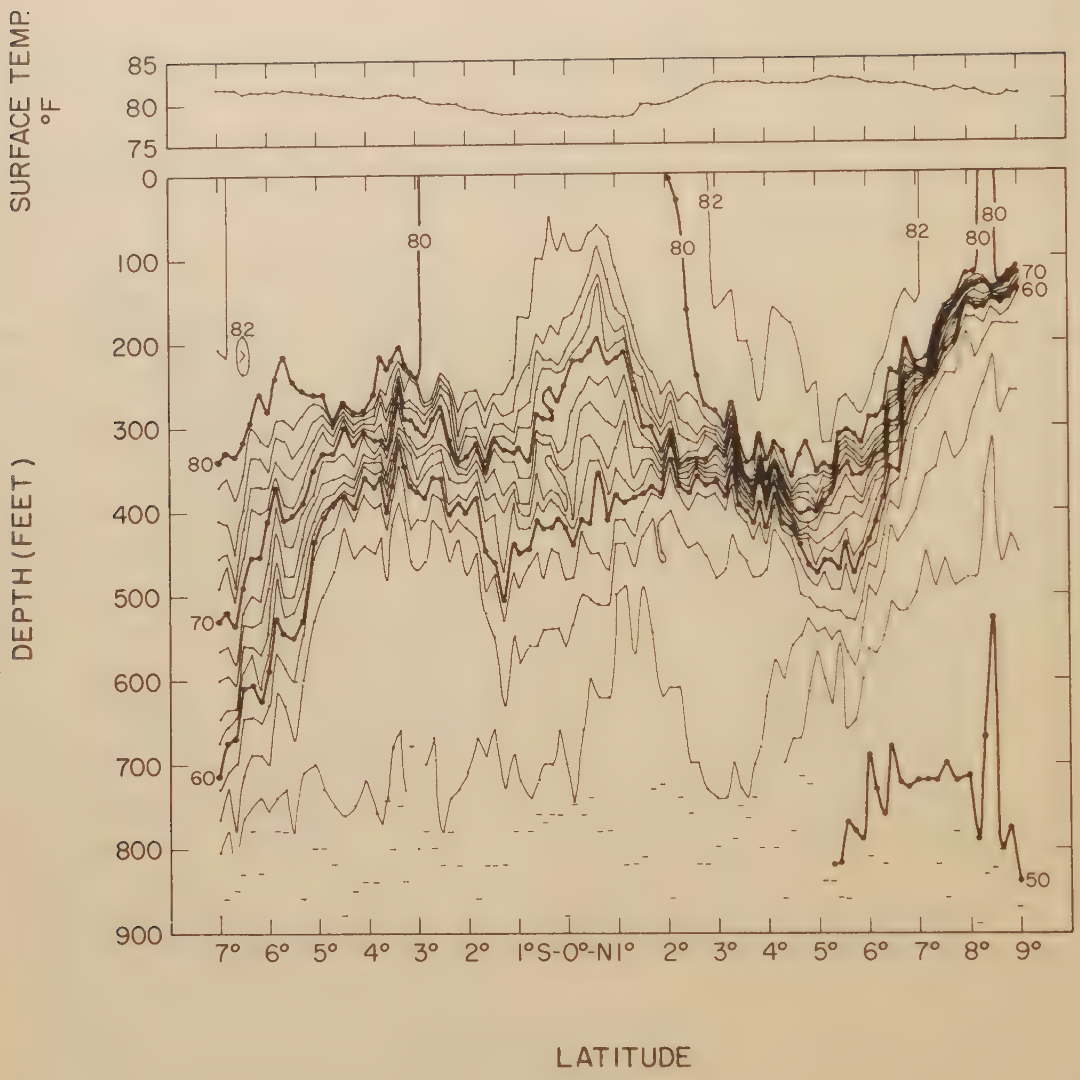


Fig. 6. --Surface temperatures and vertical temperature section. Northbound, stations 45-60, June 14-20, 1952. Upper panel. Surface temperatures as read at each bathythermograph lowering. Lower panel. Temperature section based on bathythermograph lowerings, isotherms at 2°F. interval, depth of lowering shown by small, horizontal dashed line.

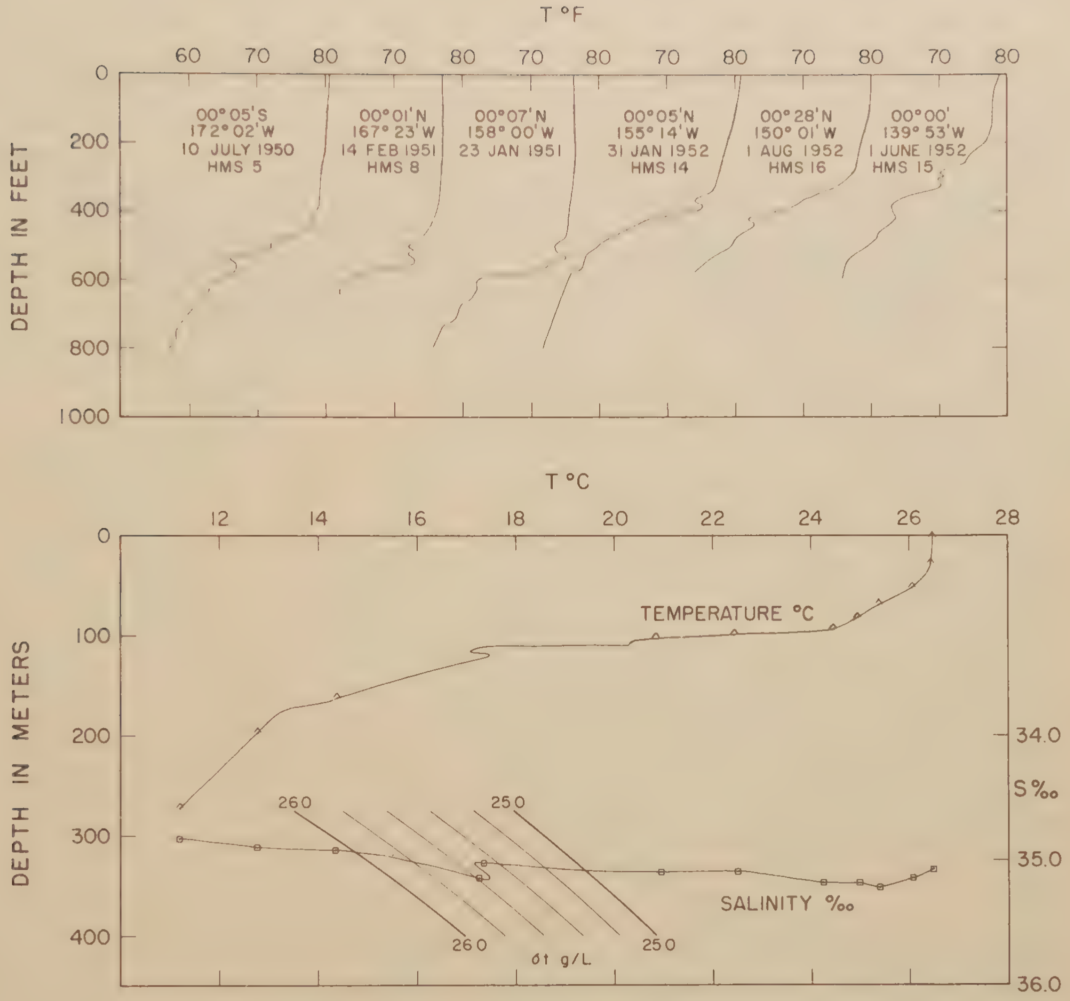


Fig. 7. -- *Upper panel.* Bathythermograph traces from five *Hugh M. Smith* cruises, various longitudes, showing temperature inversions at or near the Equator. *Lower panel.* Temperature-depth and salinity curves, *Hugh M. Smith* cruise 16, $0^{\circ}28'$N., $150^{\circ}01'$W., August 8, 1952.

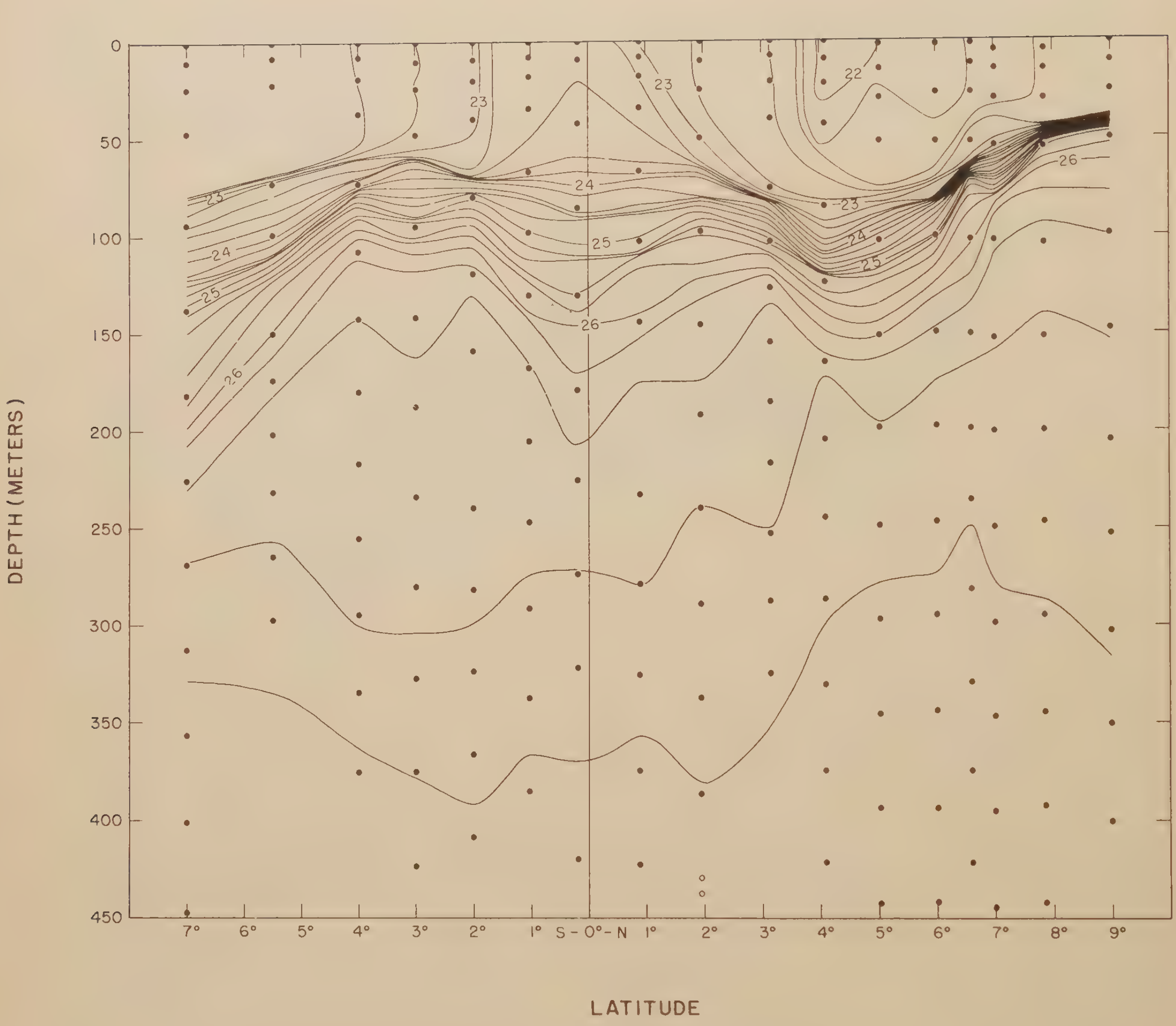


Fig. 8. -- Sigma-t. Southbound section along 140°W. longitude, 9°N. to 7°S., stations 1-17, May 28 - June 3, 1952. Sigma-t in grams per liter, isopleth interval 0.2 gm/l.

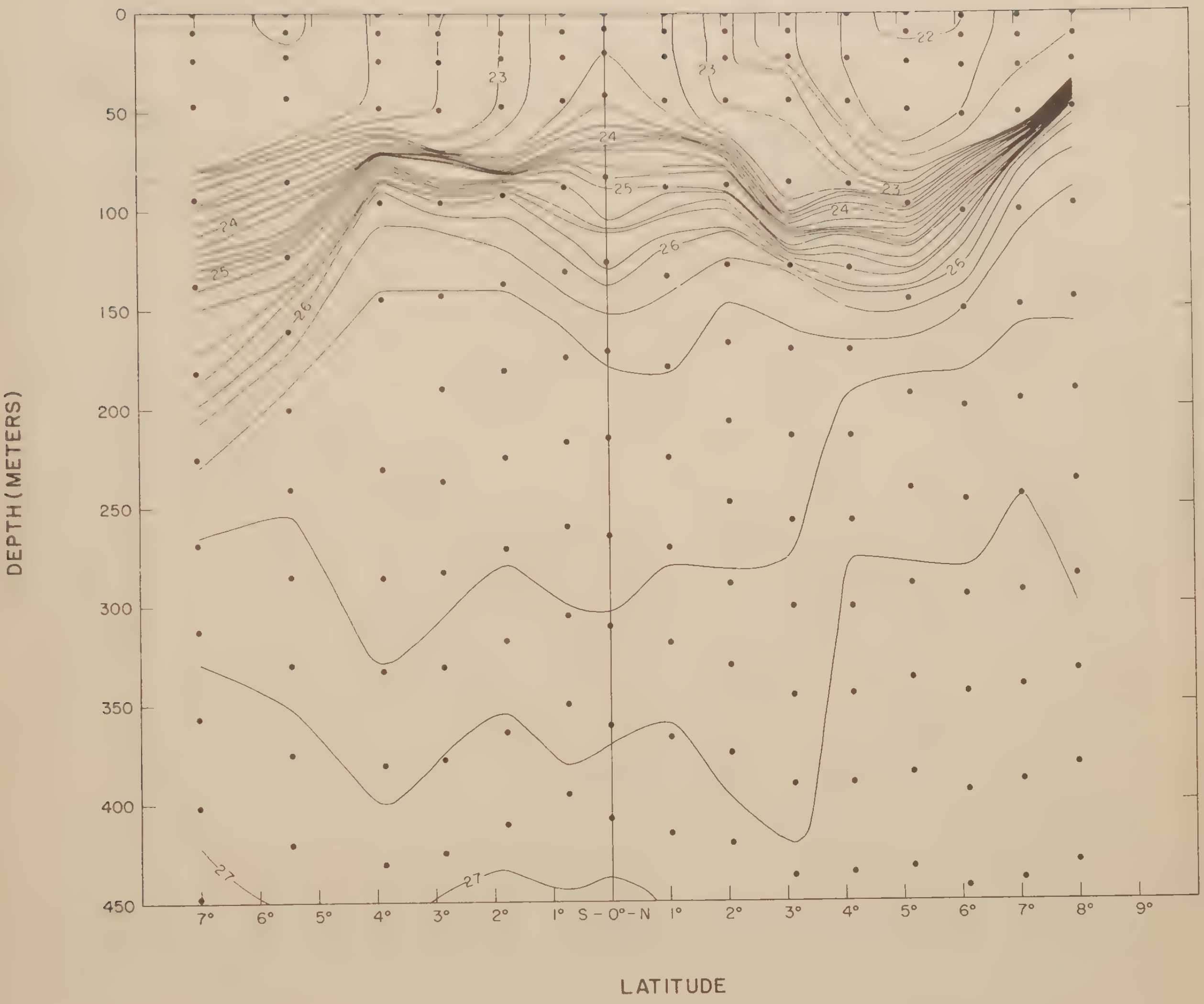


Fig. 9. -- Sigma-t. Northbound section along 140°W. longitude, 7°S. to 8°N., stations 17-31, June 3-8, 1952. Sigma-t, in grams per liter, isopleth interval 0.2 gm/l.

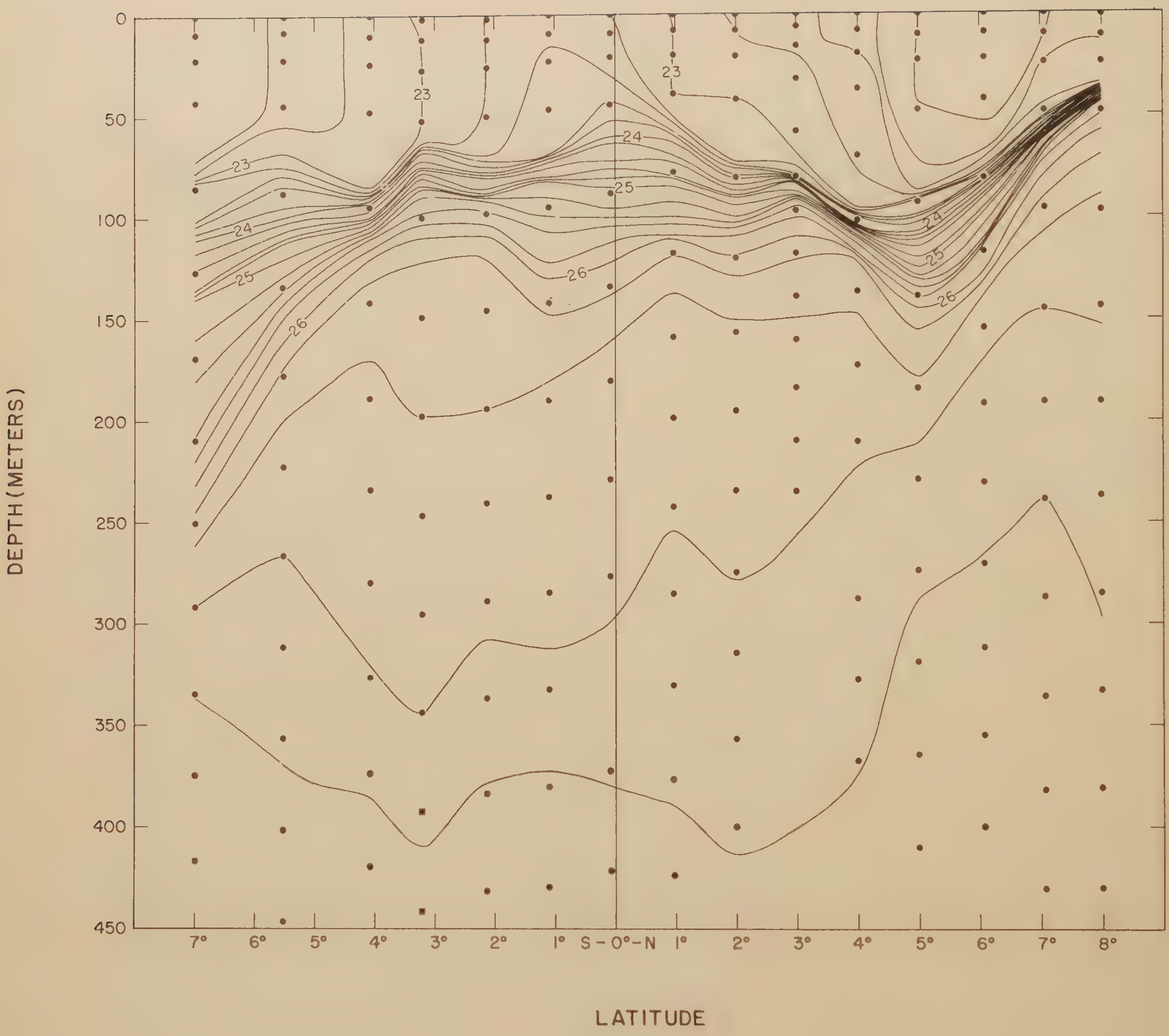


Fig. 10. -- Sigma-t. Southbound section along 140°W. longitude, 8°N. to 7°S., stations 31-45, June 8-14, 1952. Sigma-t in grams per liter, isopleth interval 0.2 gm/l.

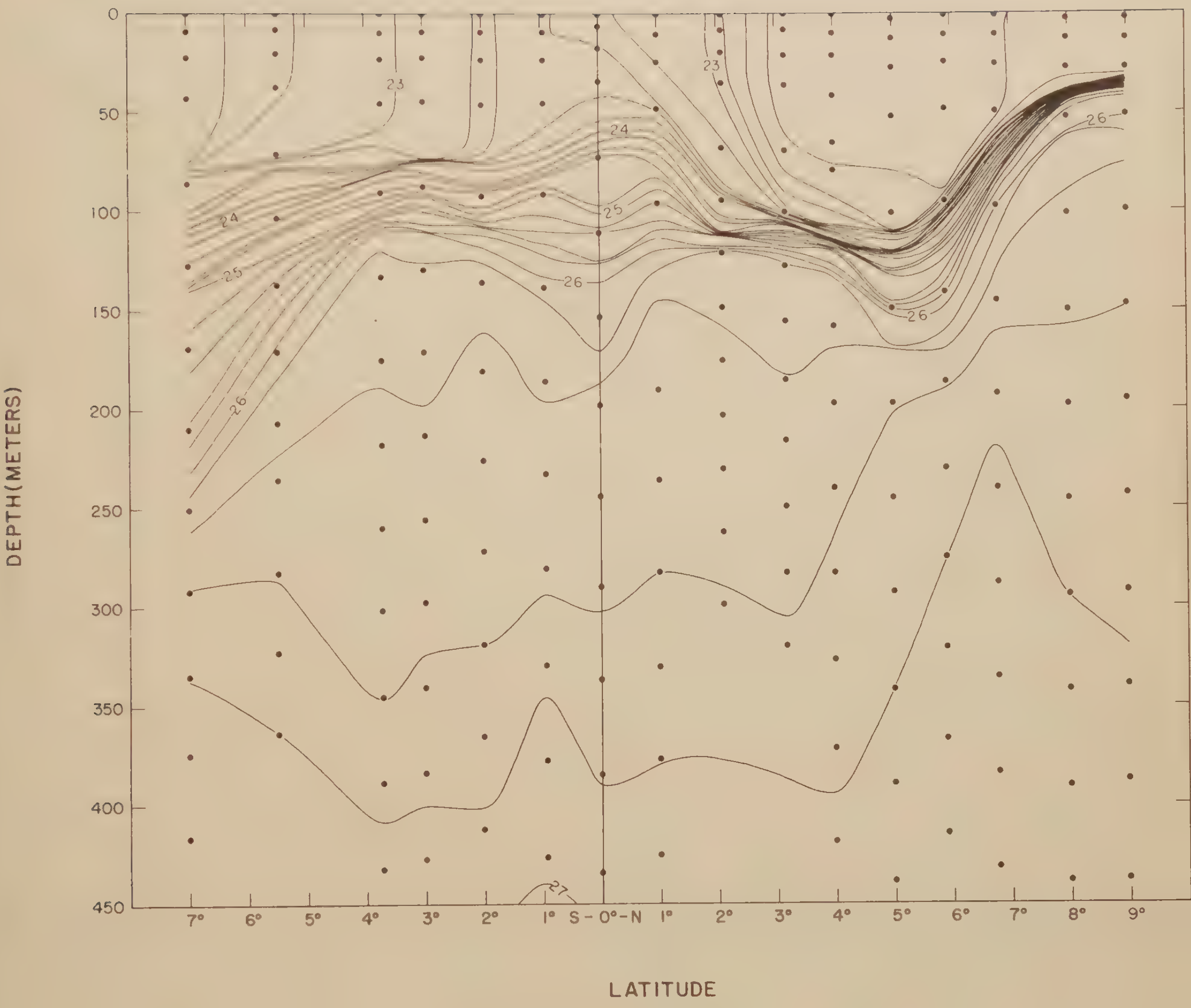


Fig. 11. -- Sigma-t. Northbound section along 140°W. longitude, 7°S. to 9°N., stations 45-60, June 14-20, 1952. Sigma-t in grams per liter, isopleth interval 0.2 gm/l.

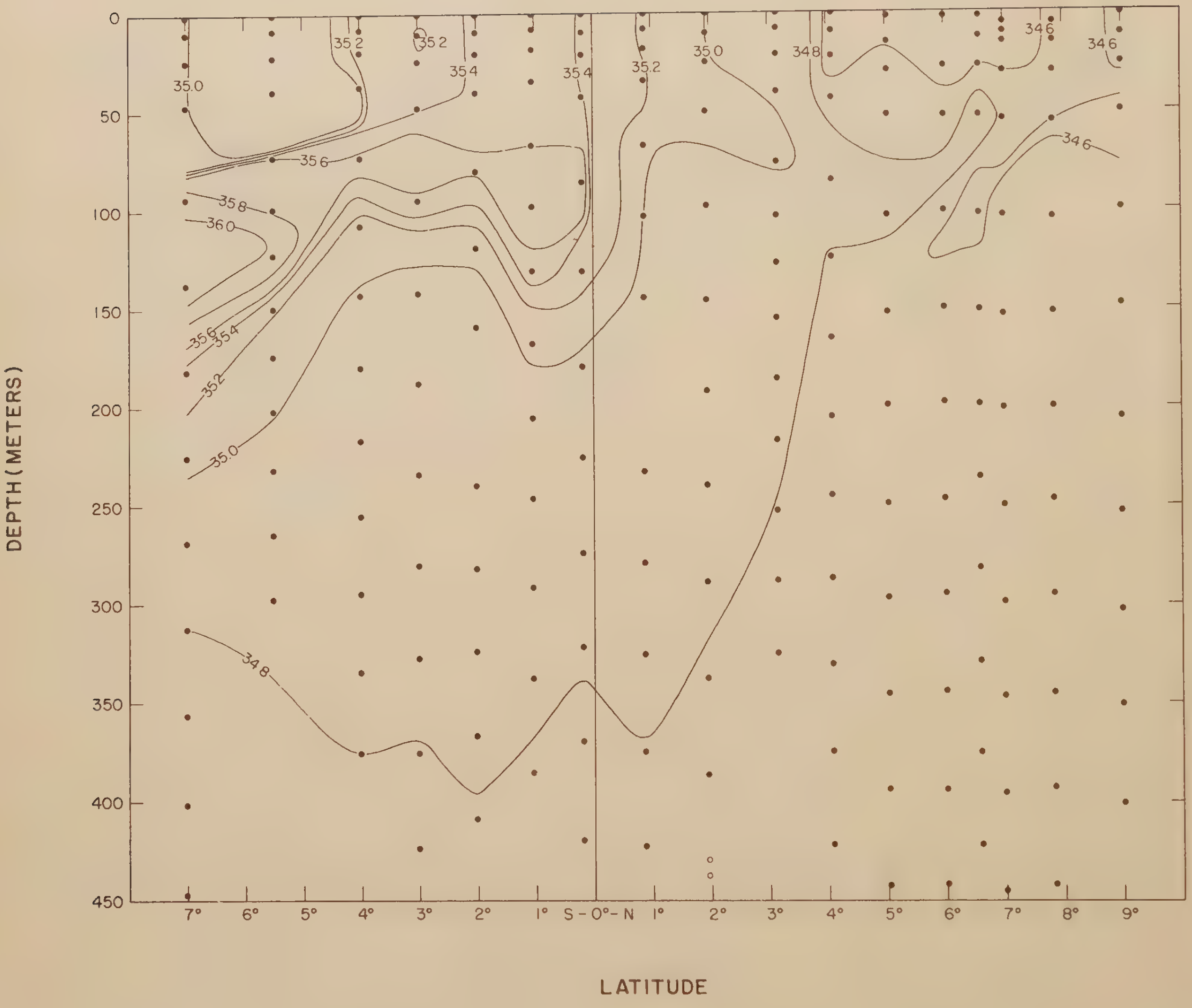


Fig. 12. -- Salinity. Southbound section along 140°W. longitude, 9°N. to 7°S., stations 1-17, May 28 - June 3, 1952. Salinity in parts per thousand, isohaline interval 0.2 °/oo.

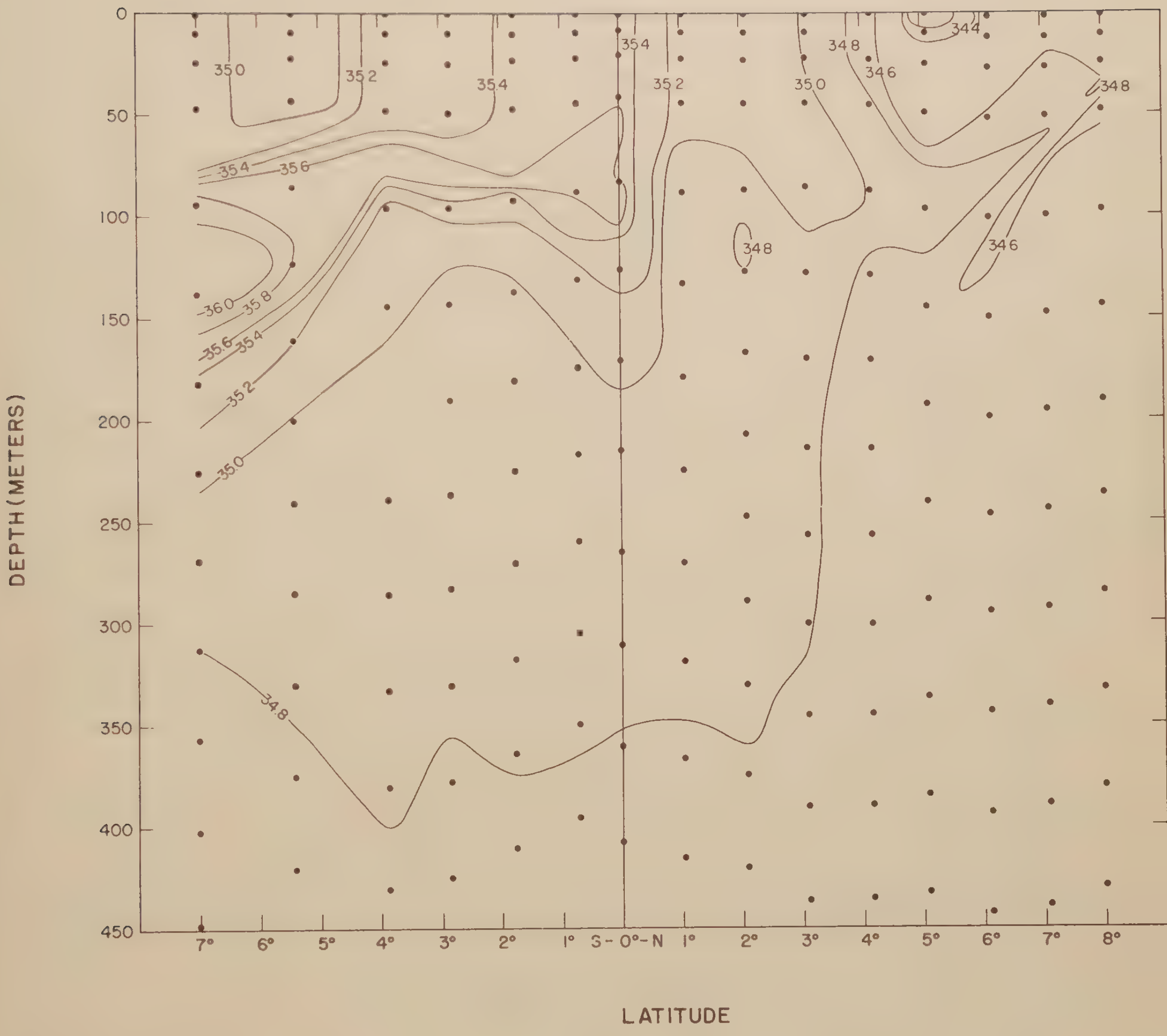


Fig. 13. -- Salinity. Northbound section along 140°W. longitude, 7°S. to 8°N., stations 17-31, June 3-8, 1952. Salinity in parts per thousand, isohaline interval 0.2 °/oo.

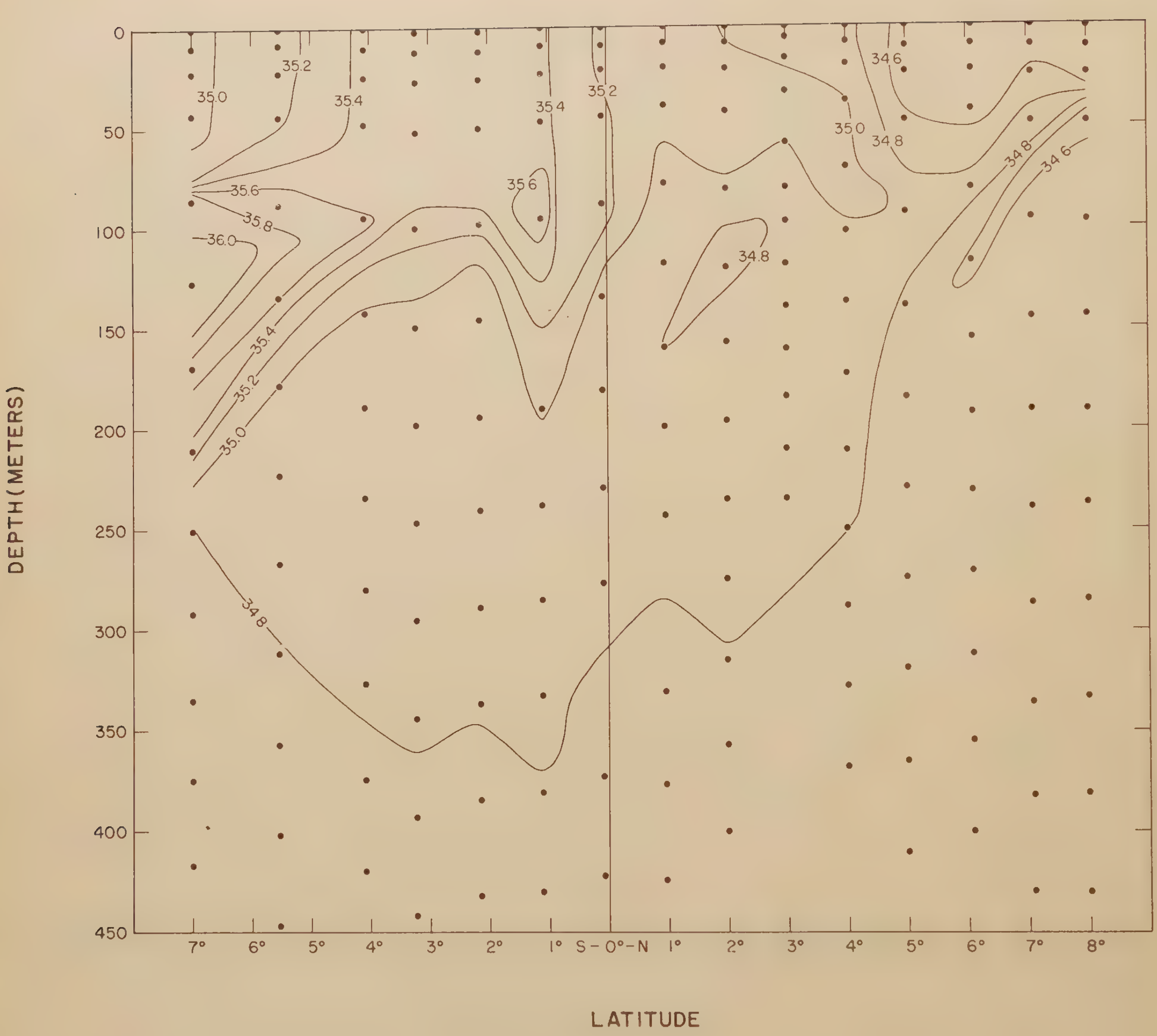


Fig. 14. -- Salinity. Southbound section along 140°W. longitude, 8°N. to 7°S., stations 31-45, June 8-14, 1952. Salinity in parts per thousand, isohaline interval 0.2 °/oo.

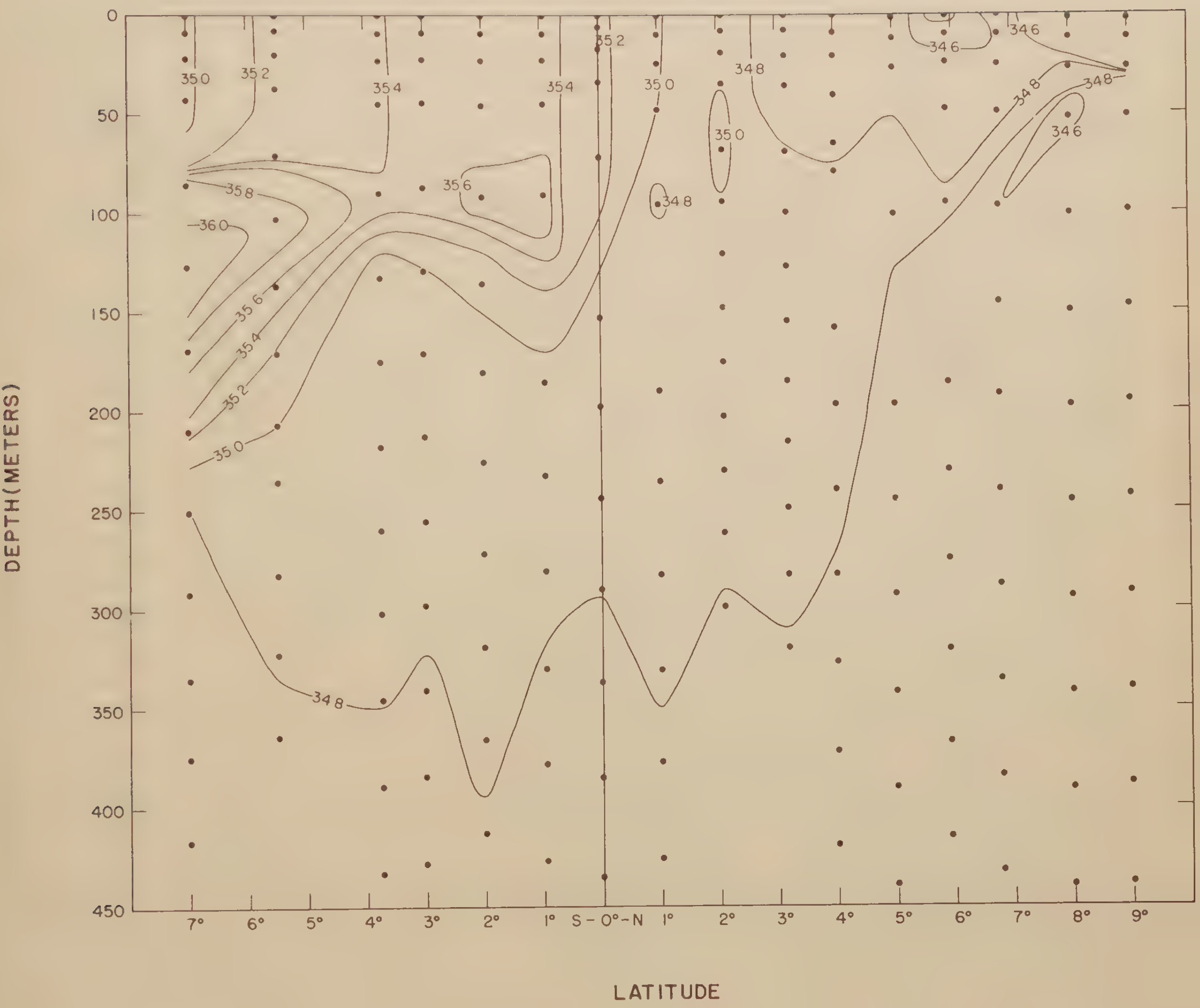


Fig. 15. -- Salinity. Northbound section along 140°W. longitude, 7°S. to 9° N, stations 45-60, June 14-20, 1952. Salinity in parts per thousand, isohaline interval 0.2 °/oo.

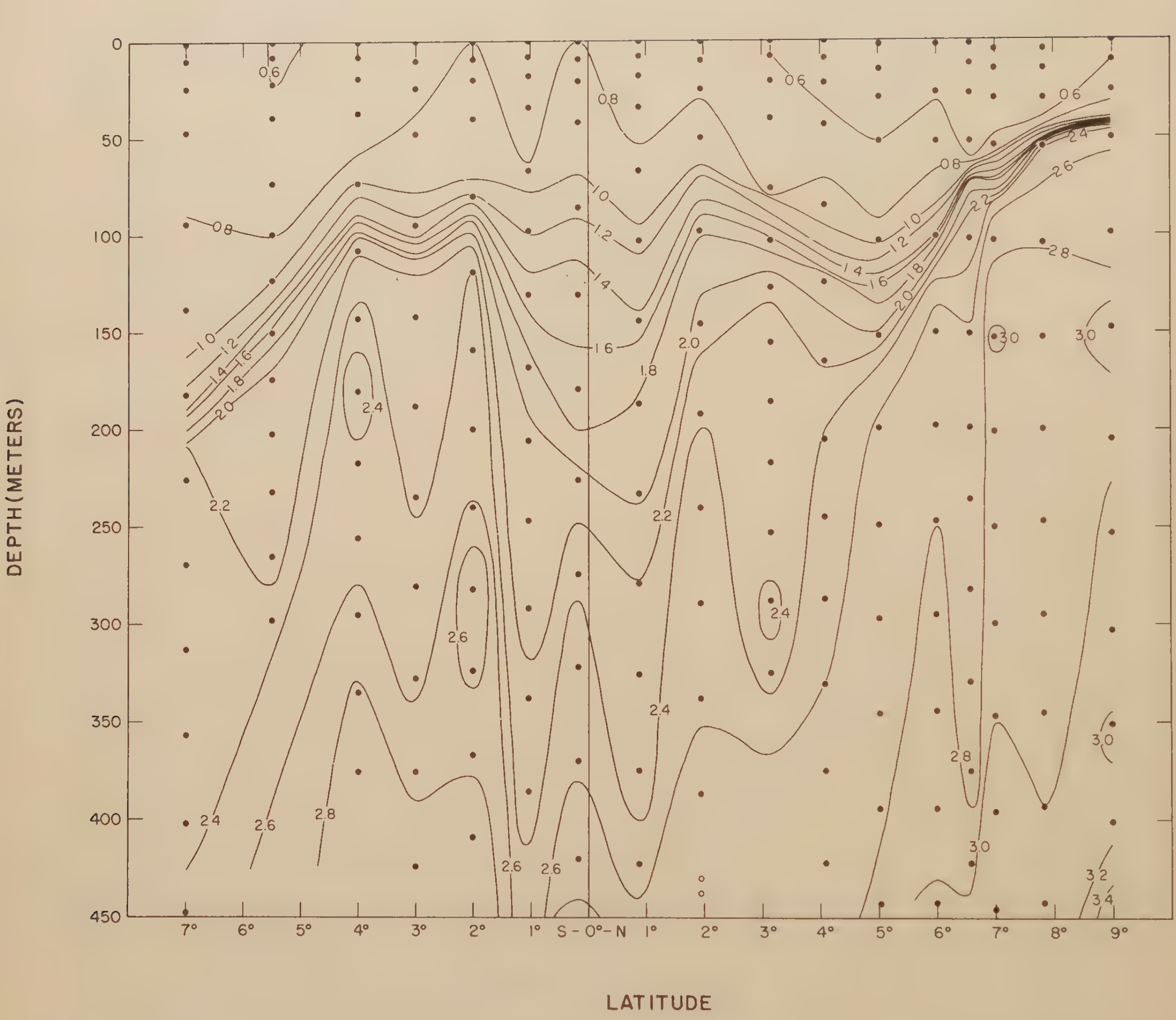


Fig. 16. -- Phosphate. Southbound section along 140°W. longitude, 9°N. to 7°S., stations 1-17, May 28 - June 3, 1952. Phosphate in microgram atoms per liter, isopleth interval 0.2 μg at/l.

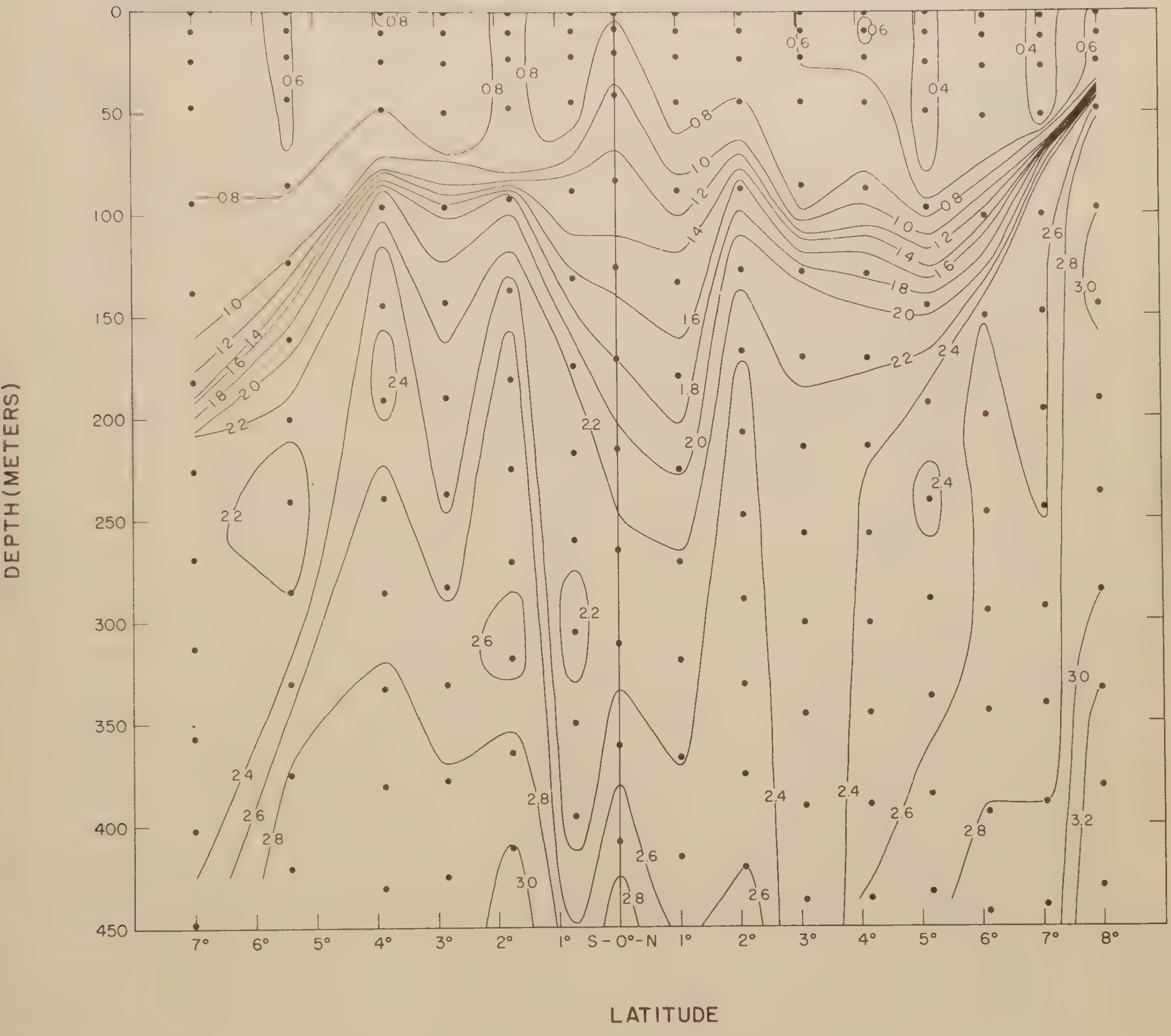


Fig. 17. -- Inorganic phosphate. Northbound section along 140°W. longitude, 7°S. to 8°N., stations 17-31, June 3-8, 1952. Phosphate in microgram atoms per liter, isopleth interval 0.2 μg at/l.

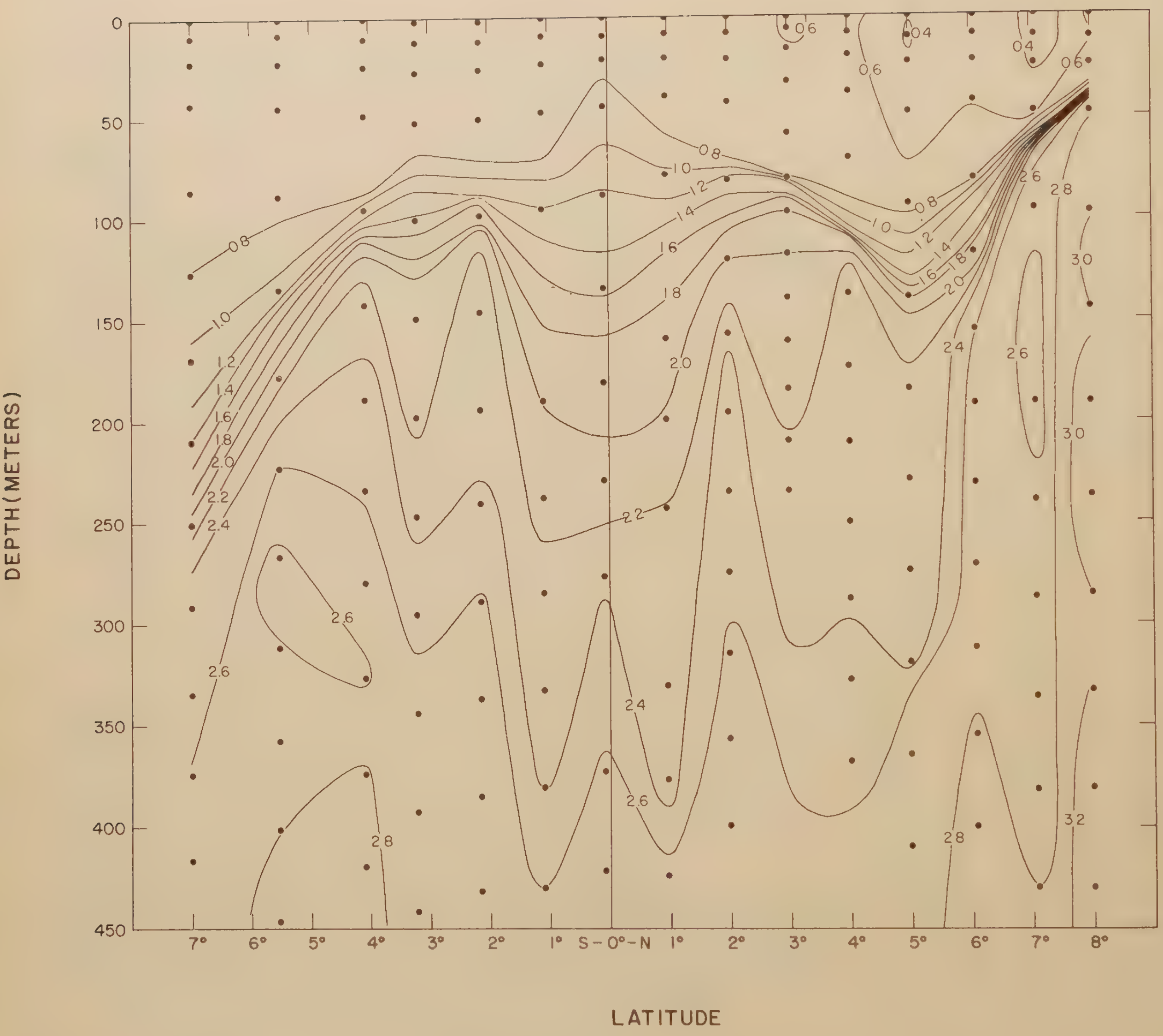


Fig. 18. -- Inorganic phosphate. Southbound section along 140°W. longitude, 8°N. to 7°S., stations 31-45, June 8-14, 1952. Phosphate in microgram atoms per liter, isopleth interval 0.2 µg at/l.

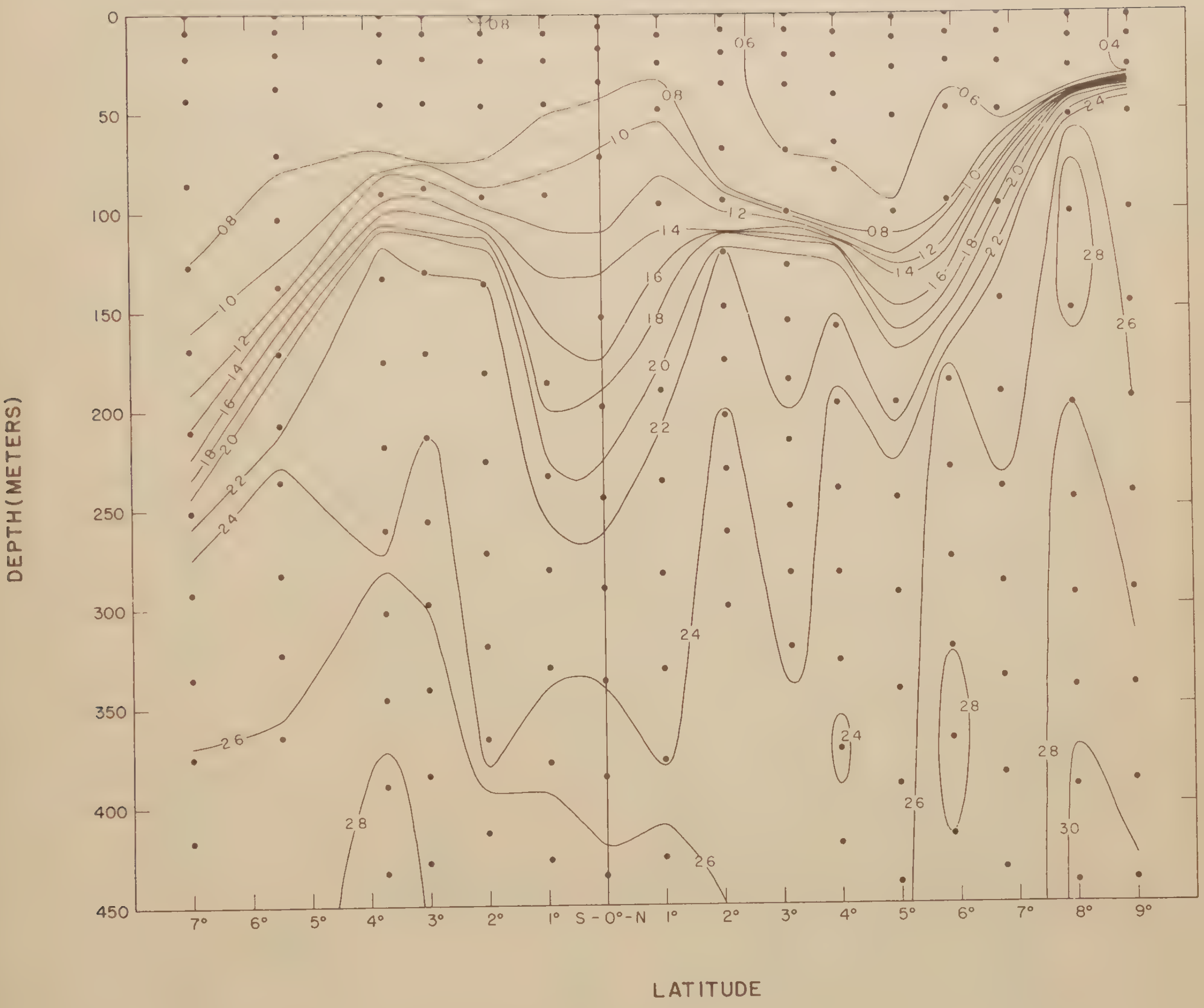


Fig. 19. -- Phosphate. Northbound section along 140°W. longitude, 7°S. to 9°N, stations 45-60, June 14-20, 1952. Phosphate in microgram atoms per liter, isopleth interval 0.2 µg at/l.

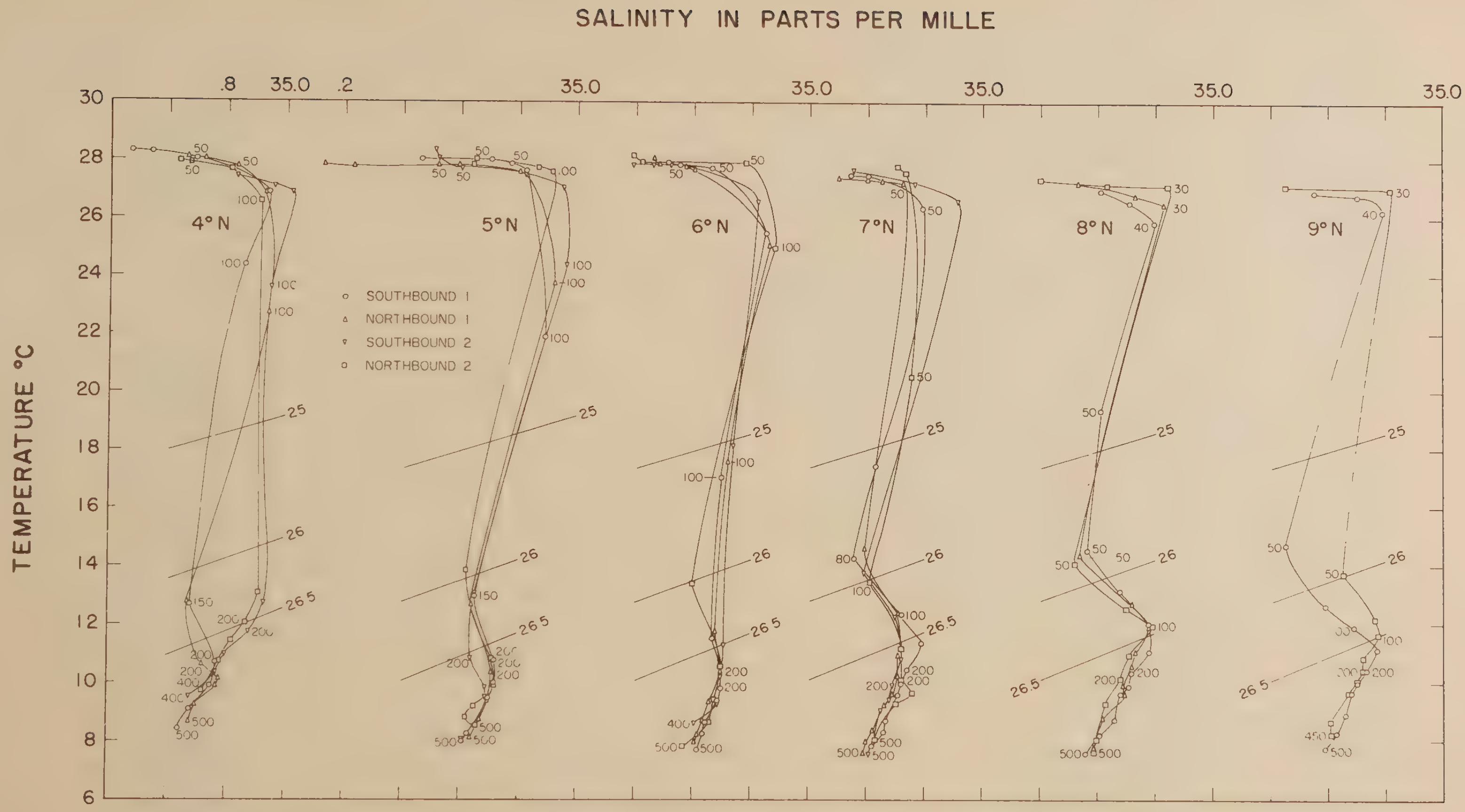


Fig. 20A. -- Temperature-salinity curves. May 28 - June 20, 1952. T-S curves for stations along each of the four legs, 9°N. to 7°S. along 140°W. longitude, have been grouped according to latitude.

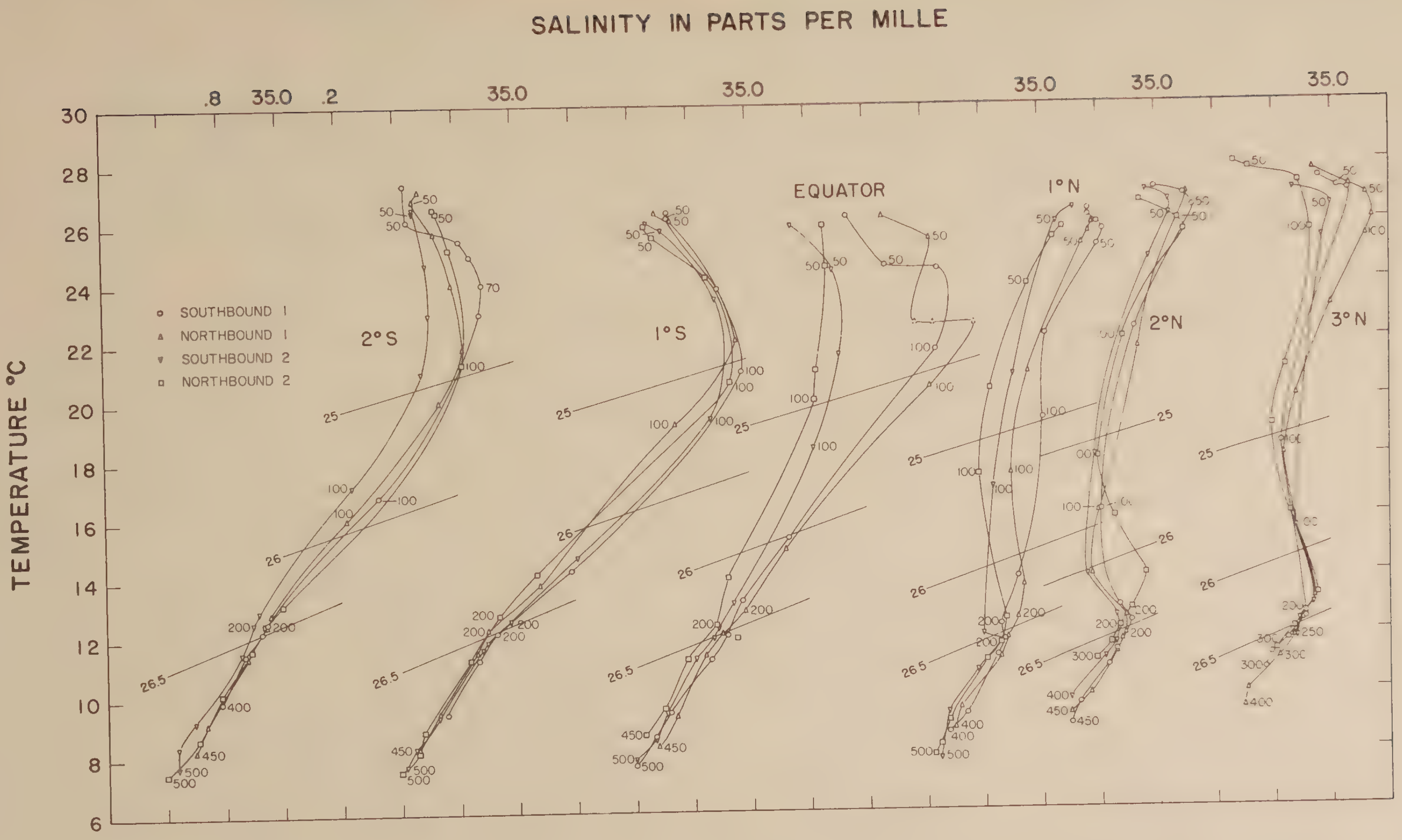


Fig. 20B. -- Temperature-salinity curves. May 28 - June 20, 1952. T-S curves for stations along each of the four legs, 9°N. to 7°S. along 140°W. longitude, have been grouped according to latitude.

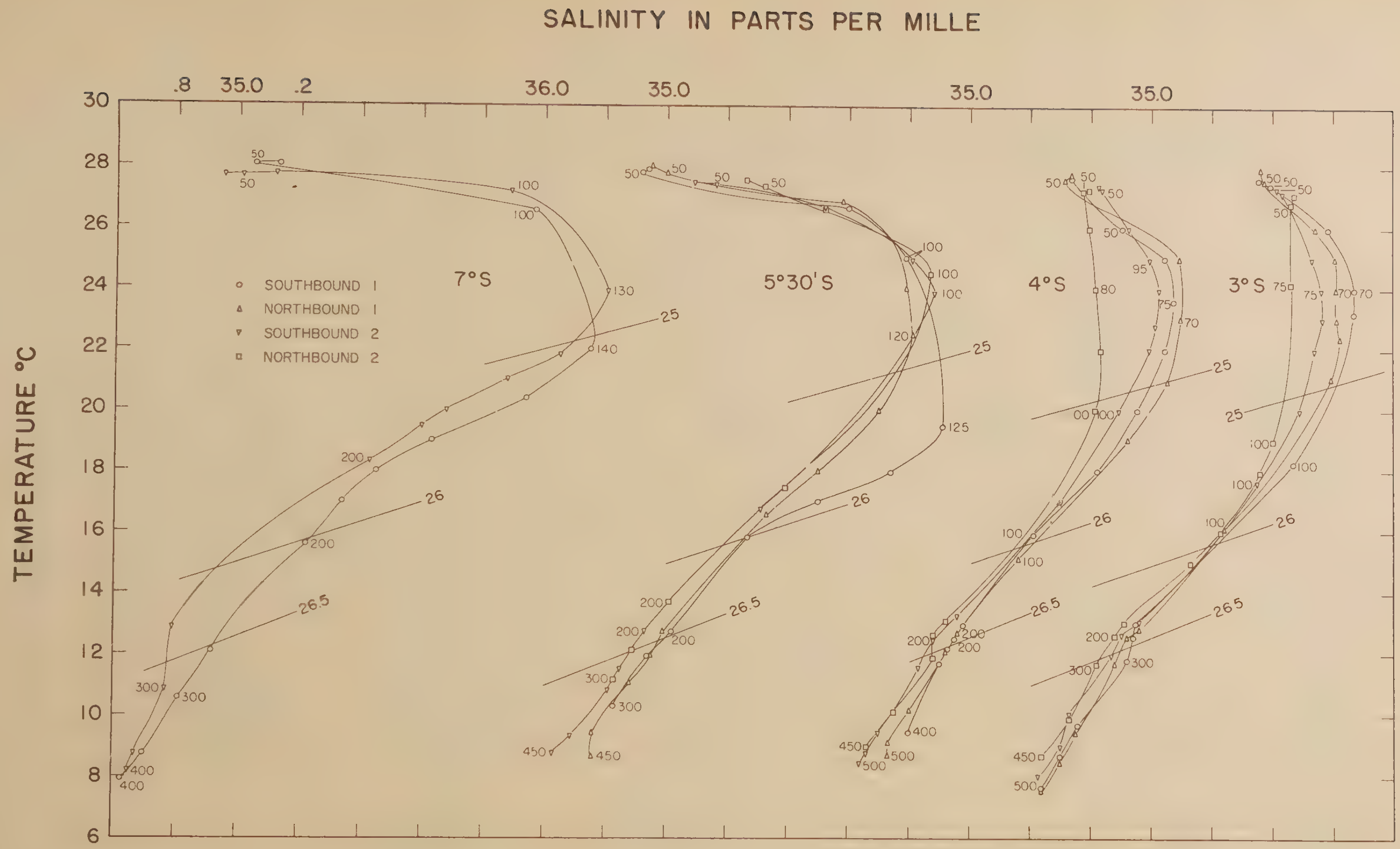
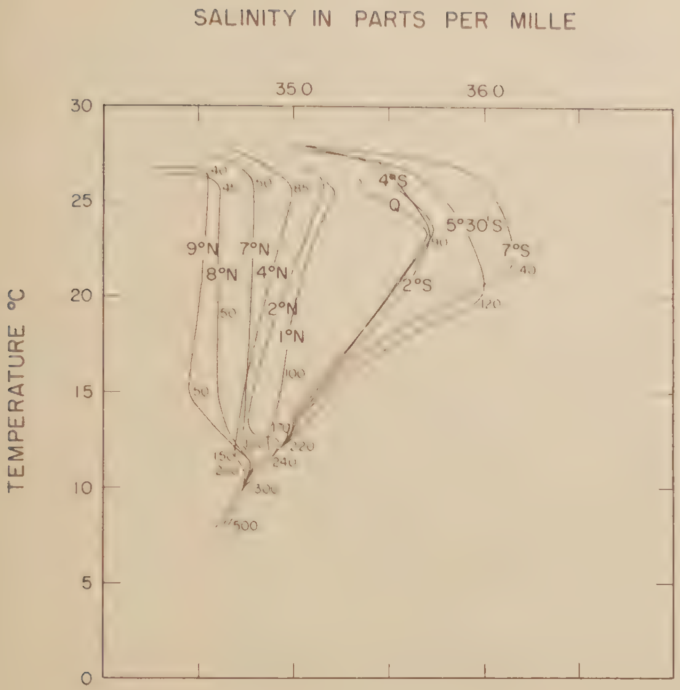


Fig. 20C. -- Temperature-salinity curves. May 28 - June 20, 1952. T-S curves for stations along each of the four legs, 9°N. to 7°S. along 140°W. longitude, have been grouped according to latitude.



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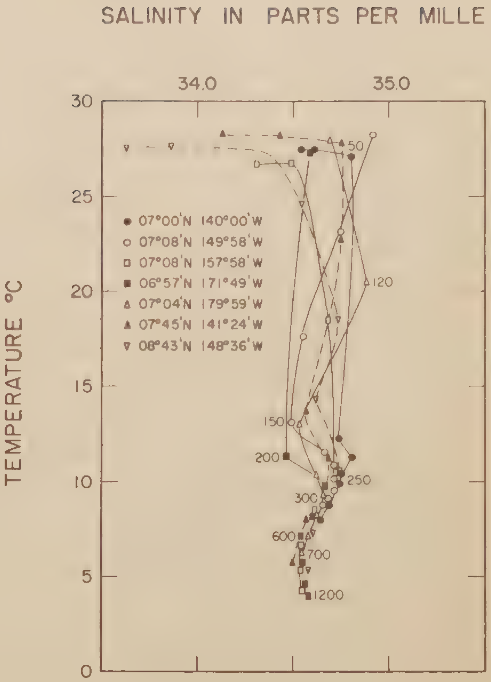

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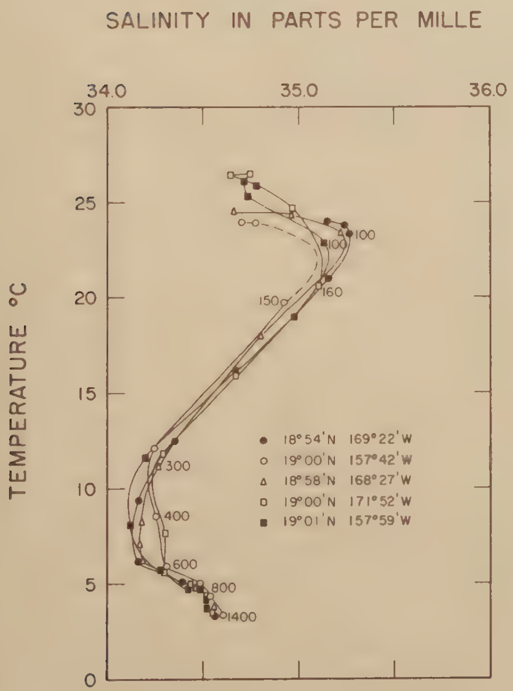


23

Fig. 21. -- Temperature-salinity curves, surface to 500 meters for selected stations from southbound leg, Hugh M. Smith cruise 15, stations 1-17, May 28 - June 3, 1952.

Fig. 22. -- Temperature-salinity curves for stations at 7°N. latitude and for various longitudes between 140°W. and 180th meridian. The two curves from vessels other than those operated by POFI are from the cruises of the Carnegie (Fleming et al. 1945) and the Albatross (Jerlov 1953).

Fig. 23. -- Temperature-salinity curves for stations at 19°N. latitude and for various longitudes between 158°W. and 171°W. longitudes.

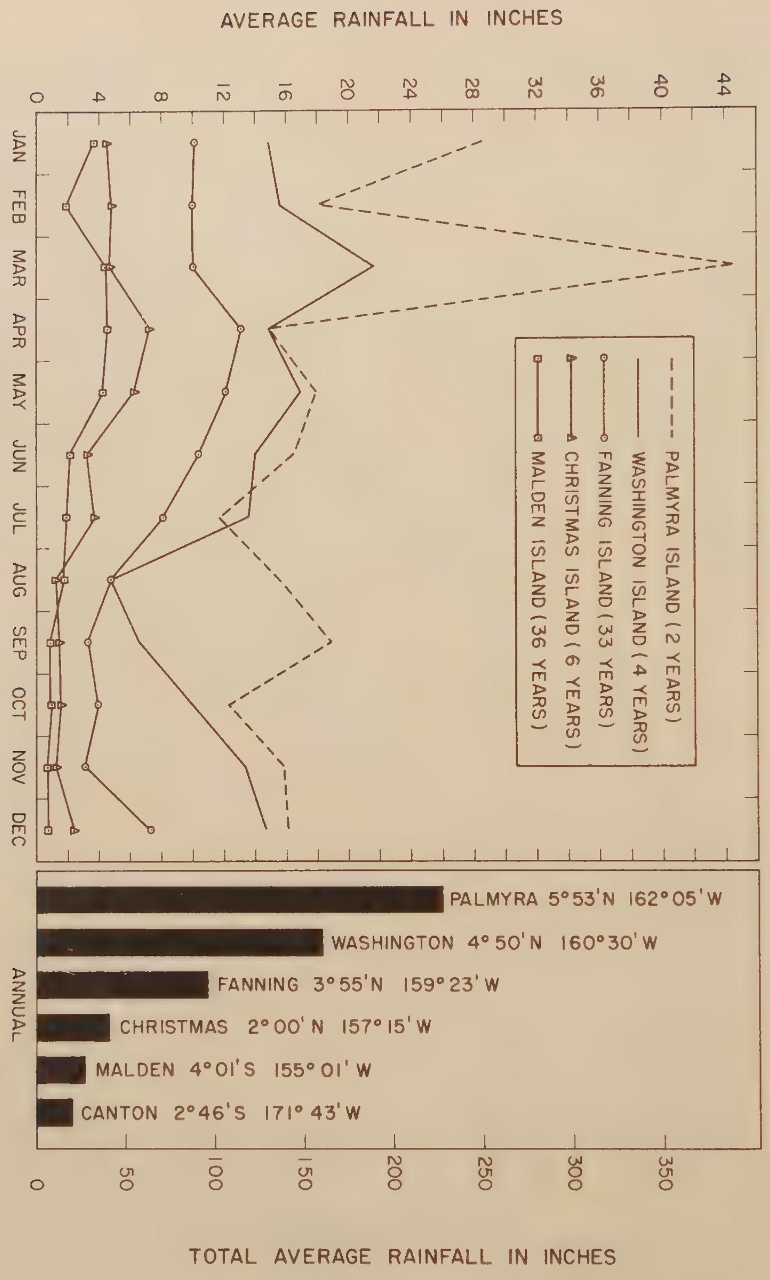
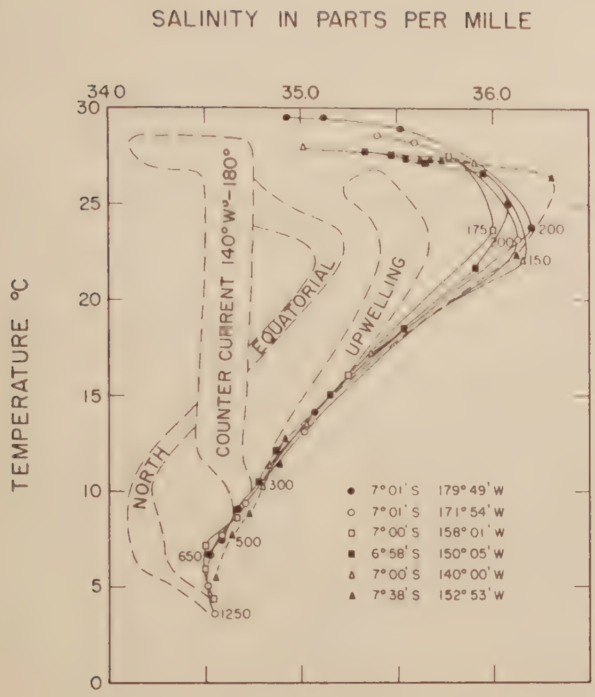


Fig. 24. --Average monthly and annual rainfall for Palmyra, Washington, Fanning, Christmas, Malden, and Canton islands.



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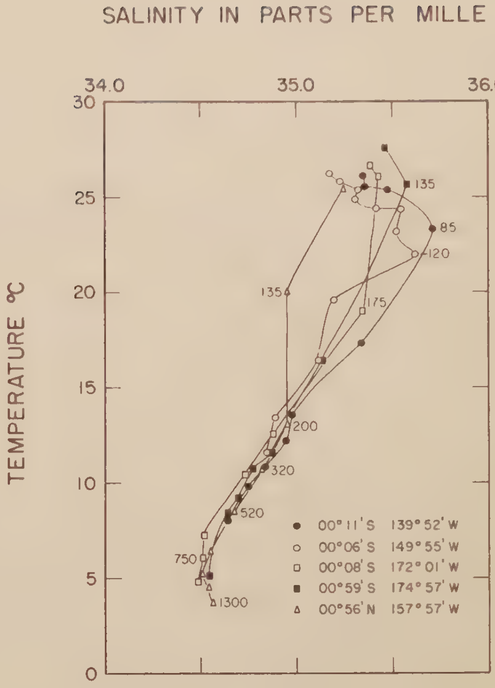

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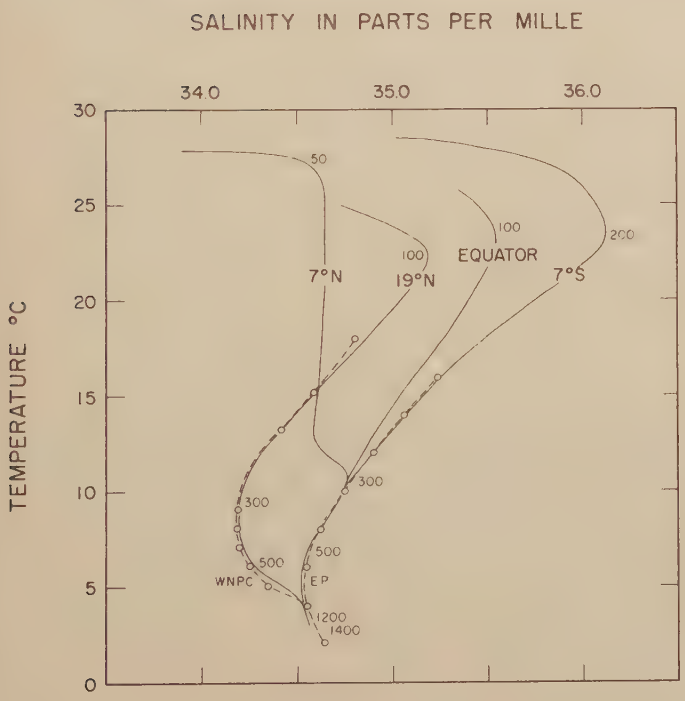


27

Fig. 25. -- Temperature-salinity curves for stations at 7°S. latitude and for various longitudes between 140°W. and 180th meridian. One curve shown is from a station made by the Albatross (Jerlov 1953).

Fig. 26. -- Temperature-salinity curves for stations near the Equator and on various longitudes between 140°W. and 180th.

Fig. 27. -- Average temperature-salinity curves for stations at 19°N., 7°N., the Equator, and 7°S., between longitudes 140°W. and the 180th meridian. The dashed lines are T-S curves for Western North Pacific Central and Equatorial Pacific waters (Sverdrup et al. 1942).

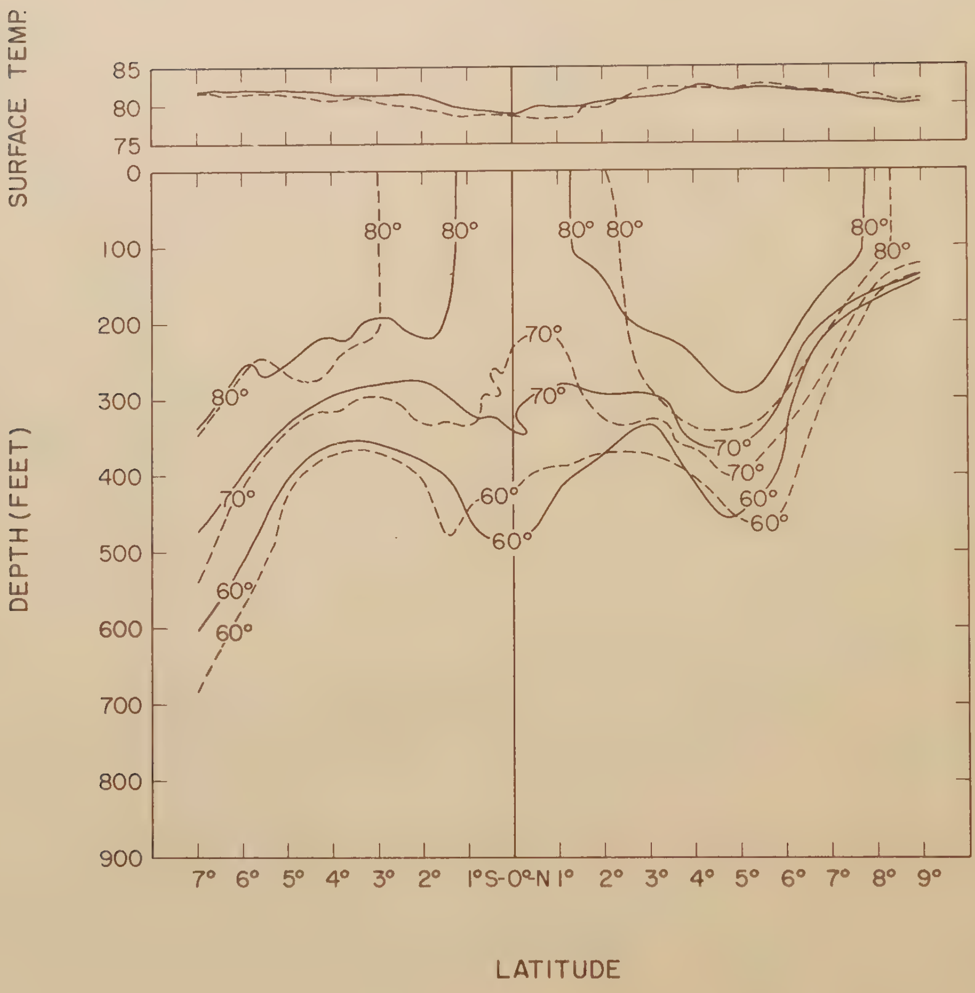


Fig. 28. -- Upper panel. Surface temperatures, first leg (solid curves) and fourth leg (broken curve) of *Hugh M. Smith* cruise 15. Lower panel. Smoothed (by inspection) 60°, 70°, and 80° isotherms for the first leg (stations 1-17, May 28 - June 3, 1952, solid curves) and fourth leg (stations 45-60, June 14-20, 1952, broken curves) of *Hugh M. Smith* cruise 15.

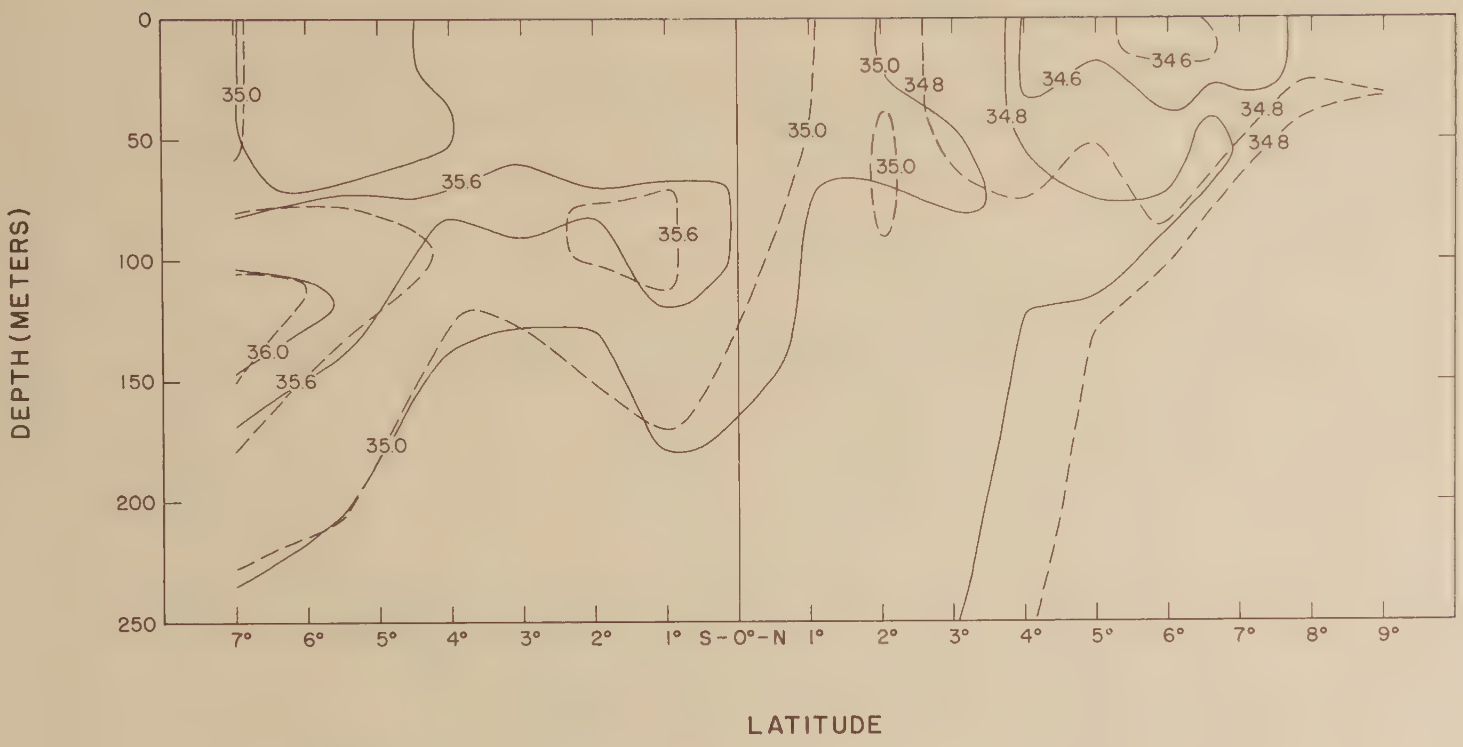


Fig. 29. -- Selected isohalines, first leg (stations 1-17, May 28 - June 3, 1952, solid curve) and the fourth leg (stations 45-60, June 14-20, 1952, broken curve) from Hugh M. Smith cruise 15. Salinity in parts per thousand.

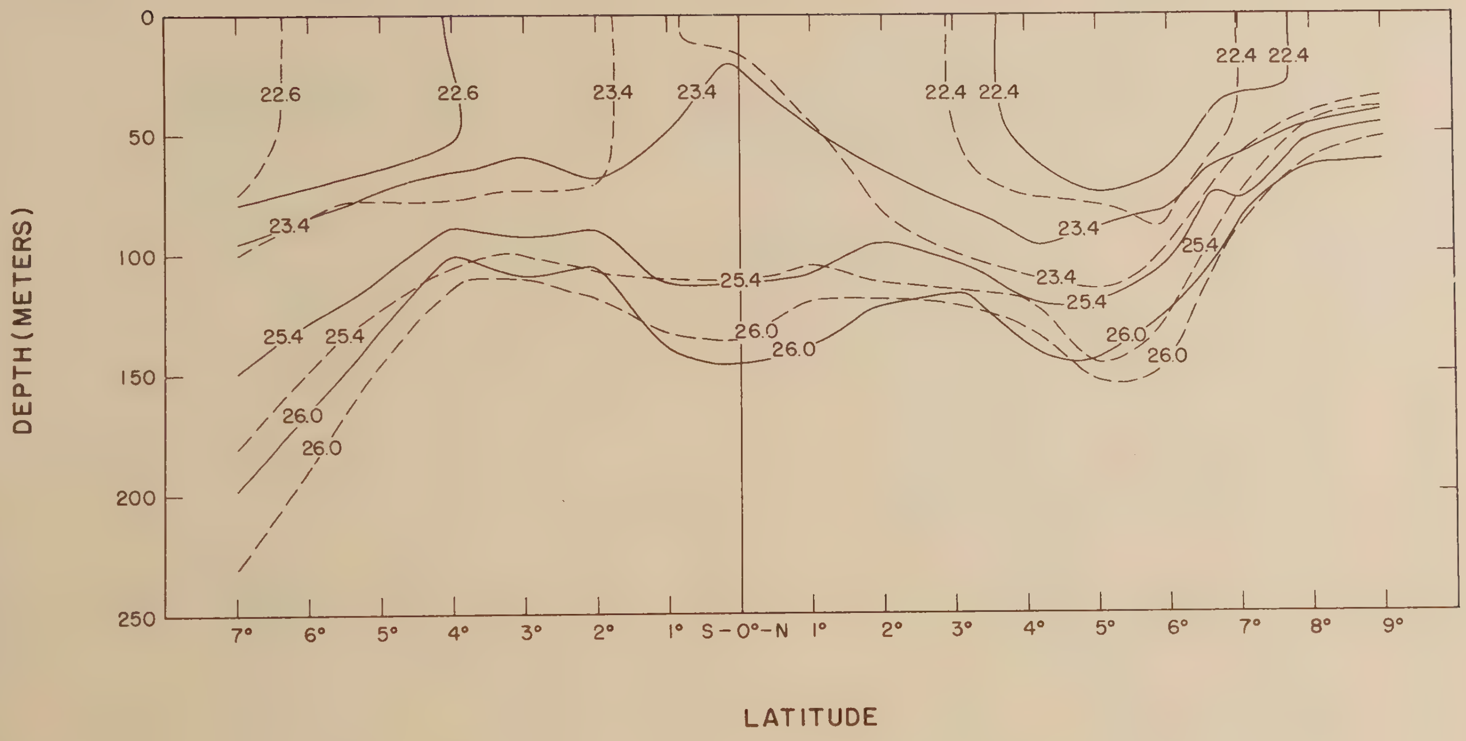


Fig. 30. -- *Selected sigma-t surfaces*, first leg (stations 1-17, May 28 - June 3, 1952, solid curves) and the fourth leg (stations 45-60, June 14-20, 1952, broken curve) of *Hugh M. Smith* cruise 15. Sigma-t in grams per liter.

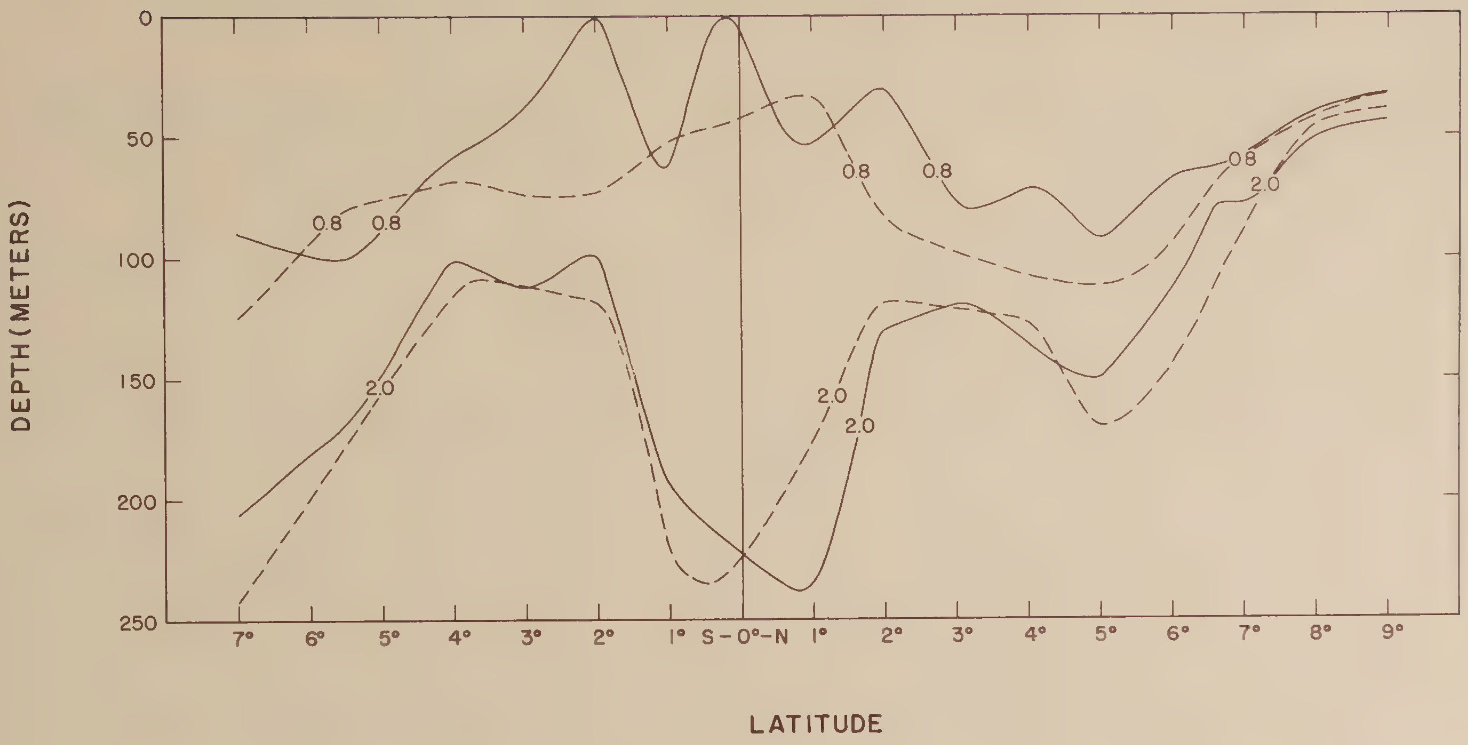


Fig. 31. -- Selected phosphate isopleths, first leg (stations 1-17, May 28 - June 3, 1952, solid curve) and the fourth leg (stations 45-60, June 14-20, 1952, broken curve) from *Hugh M. Smith* cruise 15. Inorganic phosphate in microgram atoms per liter.

Notes on the tabulated data, *Hugh M. Smith* cruise 15

1. Weather was recorded according to the ww (present weather) code in the U. S. Weather Bureau, Circular M, 8th edition, *Manual of Marine Meteorological Observations*.

2. The wind velocity was measured with an anemometer 30 M above the sea surface. The speed is recorded in knots; the direction in degrees true.

3. Any departure from the POFI standard 13-bottle cast is explained in a footnote.

4. If a value is definitely determined to be in error, it is deleted from the tabulations and an explanatory footnote appended. If a value appears to be anomalous, but there is uncertainty, the value is carried with a footnote.

5. Horizontal line(s) separating particular depths denotes more than one cast. The time and wire angle for each cast is carried in the station headings.

STATION 1

M/V *Hugh M. Smith*: Cruise 15, 8°59'N., 139°56'W., May 28, 1952.
Messenger time: first cast 1540 GCT, second cast 1605 GCT.
Weather: 50, cloud coverage 9. Wind: 040°, 21 kt. Sea: 5-8 ft.
Wire angle: first cast 12°, second cast 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
01	26.86	34.55	22.45		0.46
11	26.84	34.53	22.44		0.54
26	26.82	34.53	22.44		0.78
50	14.70	34.45	25.63		2.53
99	11.91	34.69	26.39		2.71
148	11.18	34.77	26.58		3.06
205	10.36	34.72	26.69		2.91
253	9.98	34.70	26.74		3.09
303	9.66	34.69	26.79		3.12
351	9.35	34.67	26.82		2.99
401	8.90	34.66	26.89		3.11
451	8.28	34.63	26.96		3.48
500	7.74	34.59	27.01		3.27

STATION 2

M/V Hugh M. Smith: Cruise 15, 7°51'N., 139°46'W., May 29, 1952. Messenger time: 0105 GCT. Weather: 01, cloud coverage 5. Wind: 050°, 18 kt. Sea: 5-8 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	26.90	34.61	22.48		0.43
15	26.90	34.61	22.48		0.39
30	26.82	34.62	22.51		0.40
55	15.32	34.60	25.61		2.40
104	11.86	34.79	26.47		2.68
152	10.98	34.78	26.63		2.74
200	10.31	34.72	26.70		2.40
200 2/					2.52 1/
247	9.92	34.71	26.76		2.76
295	9.64	34.70	26.80		2.76
345	9.26	34.67	26.84		2.66
345					2.74 1/
393	8.76	34.66	26.91		3.03
442	8.26	34.62	26.96		3.04
493	7.63	34.57	27.01		3.17
542					

1/ Double value when analyses disagreed by 0.05 µg at/l.

2/ Erratic unprotected thermometer, second depth determined from L-Z curve.

STATION 3

M/V Hugh M. Smith: Cruise 15, 7°00'N., 140°00'W., May 29, 1952. Messenger time: 1120 GCT. Weather: 02, cloud coverage not recorded. Wind: 050°, 18 kt. Sea: 5-8 ft. Wire angle: 00°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.47	34.54	22.24		0.48
15	27.46	34.53	22.24		0.54
30	27.42	34.60	22.30		0.54
54	26.10	34.79	22.87		0.63
103	12.26	34.72	26.34		2.70
153	11.28	34 79	26.58		3.02
201	10.42	34.74	26.70		2.72
250	9.98	34.72	26.76		2.90
299	9.59	34.71	26.81		2.91
347	9.15	34.69	26.87		3.00
396	8.73	34.67	26.92		3.10
445	8.36	34.66	26.97		3.12
495	7.90	34.62	27.01		3.29

STATION 4

M/V Hugh M. Smith: Cruise 15, 6°36'N., 139°44'W., May 29, 1952.
Messenger time: first cast 1848 GCT, second cast 1914 GCT.
Weather: 01, cloud coverage 5. Wind: 040°, 14 kt. Sea: 3-5 ft.
Wire angle: first cast 04°, second cast 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	27.71	34.60	22.21		0.45
12	27.69	34.60	22.22		0.48
27	27.64	34.60	22.23		0.41
52	27.04	34.89	22.64		0.53
102	13.46	34.55	25.97		2.06
151	11.20	34.72	26.54		2.62
199	10.17	34.70	26.71		2.70
236	9.76	34.70	26.78		2.61
236					2.66
282	9.32	34.69	26.84		2.65
329	9.06	34.69	26.89		2.66
375	8.72	34.66	26.92		2.73
422	8.32	34.64	26.96		2.88
470	7.84	34.64	27.03		2.91

STATION 5

M/V Hugh M. Smith: Cruise 15, 6°00'N., 140°00'W., May 30, 1952.
Messenger time: 0202 GCT. Weather: 02, cloud coverage 6.
Wind: 070°, 13 kt. Sea: 3-5 ft. Wire angle: 00°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	27.91	34.51	22.08		0.47
12	27.87	1/			
27	27.83	34.54	22.13		0.56
52	27.72	34.66	22.25		0.75
101	17.06	34.70	25.29		1.54
150	11.52	34.67	26.44		2.72
198	10.34	34.70	26.68		2.76
247	9.87	34.70	26.76		2.79
295	9.50	34.69	26.81		2.81
344	9.17	34.67	26.85		2.92
394	8.73	34.66	26.92		2.91
442	8.33	34.64	26.96		3.04
491	7.86	34.63	27.02		3.10

1/ No sample.

STATION 6

M/V *Hugh M. Smith*: Cruise 15, 5°02'N., 139°58'W., May 30, 1952. Messenger time: 1035 GCT. Weather: 50, cloud coverage not recorded. Wind: 030° (variable), 8 kt. Sea: 1-3 ft. Wire angle: 03°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	28.03	34.46	22.00		0.45
15	28.04	34.51	22.04		0.48
29	27.96	34.75	22.24		0.53
52	27.87	34.77	22.29		0.60
103	21.10	34.88	24.39		0.97
152	12.78	34.65	26.18		2.05
199	10.80	34.72	26.61		2.65
249	10.00	34.72	26.75		2.71
297	09.50	34.70	26.82		2.58
346	09.12	34.68	26.87		2.69
394	08.78	34.66	26.91		2.75
443	08.34	34.63	26.95		2.92
492	08.04	34.61	26.98		2.90

STATION 7

M/V *Hugh M. Smith*: Cruise 15, 4°05'N., 139°58'W., May 30, 1952. Messenger time: 1835 GCT. Weather: 03, cloud coverage 7. Wind: 180°, 9 kt. Sea: 1-3 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.25	34.47	21.94		0.43
09	28.24	34.45	21.92		0.48
22	28.24	34.49	21.95		0.55
43	28.03	34.65	22.14		0.63
85	25.94	34.97	23.05		0.94
124	16.73	34.77	25.42		1.84
165	11.52	34.66	26.43		2.17
205	10.72	34.77	26.67		2.42
245	10.29	34.77	26.74		2.54
287	10.03	34.76	26.78		2.54
331	09.54	34.70	26.81		2.60
375	09.30	34.69	26.85		2.71
422	08.94	34.68	26.90		2.73

STATION 8

M/V Hugh M. Smith: Cruise 15, 3°09'N, 139°53'W., May 31, 1952.
Messenger time: 0310 GCT. Weather: 01, cloud coverage 3.
Wind: 180°, 4 kt. Sea: 1-3 ft. Wire angle: 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.38	34.96	22.59		0.60
08	27.36	34.96	22.60		0.60
21	27.10	34.97	22.69		0.64
40	27.06	34.98	22.70		0.67
76	26.93	35.06	22.81		0.66
103	17.38	34.81	25.29		1.64
127	13.20	34.93	26.32		2.12
155	12.26	34.91	26.49		2.30
186	11.82	34.86	26.53		2.32
217	11.48	34.83	26.57		2.37
253	11.16	34.79	26.60		2.35
288	10.88	34.79	26.65		2.41
325	10.19	34.71	26.71		2.37

STATION 9

M/V Hugh M. Smith: Cruise 15, 1°57'N, 140°03'W., May 31, 1952.
Messenger time: 1210 GCT. Weather: 02, cloud coverage 1.
Wind: 110°, 4 kt. Sea: 1-3 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.13	35.00	22.70		0.71
10	27.12	35.00	22.70		0.78
25	26.97	35.03	22.77		0.79
50	26.46	35.13	23.01		0.85
98[1]	16.55	34.81	25.49		1.76
146	12.98	34.86	26.31		2.07
192	12.46	34.91	26.45		2.40
240	11.48	34.87	26.60		2.47
289	11.00	34.84	26.67		2.47
338	10.35	34.77	26.73		2.55
387	09.79	34.76	26.82		2.69
430	09.12	34.70	26.89		2.79
438					
488	08.44	34.69	26.98		2.89

[1] Depth in question due to erratic unprotected thermometer.

STATION 10

M/V Hugh M. Smith: Cruise 15, 0°53'N., 140°02'W., May 31, 1952. Messenger time: 2113 GCT. Weather: 02, cloud coverage 1. Wind: 120°, 5 kt. Sea: 1-3 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.42	35.17	23.05		0.70
08	26.24	35.17	23.11		0.67
18	26.01	35.18	23.18		0.73
34	25.63	35.22	23.34		0.72
67	23.89	35.08	23.75		0.91
103	18.94	35.01	25.06		1.05
144	14.29	34.93	26.09		1.48
187	12.45	1/			1.82
233	11.88	34.86	26.52		1.98
279	11.56	34.87	26.59		2.21
326	10.78	34.83	26.70		2.34
375	09.68	34.78	26.85		2.29
423	08.94	34.70	26.91		2.55

1/ No sample.

STATION 11

M/V Hugh M. Smith: Cruise 15, 0°11'S., 139°52'W., June 1, 1952. Messenger time: 0618 GCT. Weather: 25, cloud coverage 8. Wind: 090°, 6 kt. Sea: 1-3 ft. Wire angle: 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.24	35.34	23.23		0.80
09	26.12	35.35	23.28		0.83
21	25.71	35.34	23.40		0.82
42	25.56	35.46	23.54		0.90
86	23.46	35.70	24.35		1.14
131	17.46	35.33	25.67		1.44
179	13.70	34.98	26.25		1.71
226	12.36	34.95	26.49		2.07
274	11.55	34.88	26.60		2.38
322	10.90	34.83	26.68		2.44
370	09.87	34.75	26.80		2.54
420	09.12	34.71	26.89		2.73
469	08.18	34.65	26.99		2.91

STATION 12

M/V Hugh M. Smith: Cruise 15, 1°02'S., 139°52'W., June 1, 1952. Messenger time: 1349 GCT. Weather: 63, cloud coverage not recorded. Wind: 090°, 20 kt. Sea: 3-5 ft. Wire angle: 48°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	35.53	23.33		0.71
08	26.60	35.52	23.26		0.77
18	26.58	35.52	23.26		0.76
34	26.39	35.53	23.33		0.72
67[1]	25.32	35.60	23.72		0.87
98	21.29	35.78	25.03		1.17
131	16.92	35.44	25.89		1.52
168	13.24	35.07	26.42		1.83
206	12.06	34.92	26.54		2.07
247[1]	11.84	34.90	26.56		2.12
292	11.34	34.88	26.64		2.12
338	10.58	34.83	26.74		2.27
386	09.75	34.78	26.84		2.32

[1] Depth in question due to erratic unprotected thermometer

STATION 13

M/V Hugh M. Smith: Cruise 15, 2°00'S., 139°50'W., June 1, 1952. Messenger time: 2128 GCT. Weather: 03, cloud coverage 2. Wind: 100°, 12 kt. Sea: 5-8 ft. Wire angle: 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.40	35.43	22.93		0.80
09	27.36	35.44[1]	22.95		0.82
20	27.28	35.43	22.97		0.83
40	27.26	35.43	22.98		0.83
80	21.28	35.62	24.91		1.31
119	14.08	35.07	26.24		2.40
159	12.53	34.96	26.47		2.48
200	12.26	[2]			2.52
240	11.95	34.90	26.54		2.62
282	11.62	34.87	26.58		2.58
324	11.29	34.87	26.64		2.56
367	10.78	34.83	26.70		2.75
409	09.47	34.78	26.89		3.04

[1] Interpolated value.

[2] Sample lost.

STATION 14

M/V Hugh M. Smith: Cruise 15, 3°00'S., 139°52'W., June 2, 1952.
Messenger time: 0500 GCT. Weather: 03, cloud coverage 3.
Wind: 110°, 14 kt. Sea: 3-5 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.61	35.35	22.80		0.70
10	27.60	35.19	22.70		0.66
24	27.59	35.36	22.82		0.74
48	27.48	35.37	22.86		0.87
95 1/	18.45	35.49	25.55		1.35
142	13.10	34.96	26.36		2.27
188	12.57	34.94	26.45		2.20
234	12.40	34.93	26.47		2.35
281	12.04	34.94	26.55		2.57
328	11.04	34.86	26.68		2.57
376	10.10	34.79	26.79		2.77
424	09.15	34.73	26.90		2.85
473	08.16	34.67	27.01		2.86

1/ Depth in question due to erratic unprotected thermometer.

STATION 15

M/V Hugh M. Smith: Cruise 15, 4°00'S., 140°05'W., June 2, 1952.
Messenger time: first cast 1333 GCT, second cast 1350 GCT.
Weather: 02, cloud coverage 3. Wind: 090°, 14 kt. Sea: 3-5 ft.
Wire angle: first cast 38°, second cast 40°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.66	35.33	22.77		0.66
08	27.64	35.34	22.79		0.76
19	27.66	35.31	22.76		0.72
37	27.65	34.97	22.51		0.73
73	24.54	35.66	24.00		1.00
108	14.84	35.12	26.12		2.14
143	13.00	34.98	26.39		2.42
180	12.64	34.96	26.45		2.35
217	12.38	34.94	26.49		2.47
256	12.12	34.93	26.53		2.56
295	11.74	34.90	26.58		2.71
335	10.76	34.83	26.70		2.84
376	09.91	34.80	26.83		2.88

STATION 16

M/V Hugh M. Smith: Cruise 15, 5°30'S., 139°57'W., June 3, 1952.
Messenger time: 0504 GCT. Weather: 02, cloud coverage 3.
Wind: 100°, 8 kt. Sea: 1-3 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.93	34.94	22.39		0.61
08	27.93	34.95	22.40		0.62
22	27.91	34.92	22.38		0.60
39	27.37	34.92	22.40		0.61
73	26.71	35.60	23.28		0.73
99	25.21	35.78	23.88		0.78
123	19.52	35.91	25.60		1.00
150[1]	15.83	35.27	26.01		1.65
174	13.66	35.08	26.34		2.02
202	12.64	35.01	26.49		2.00
232	12.22	34.96	26.53		2.05
265	11.65	34.93	26.62		2.10
298[1]	10.44	34.84	26.77		2.36

[1] Depth in question due to erratic unprotected thermometer.

STATION 17

M/V Hugh M. Smith: Cruise 15, 7°00'S., 139°58'W., June 3, 1952.
Messenger time: 1545 GCT. Weather: 62, cloud coverage 7.
Wind: 180°, 2 kt. Sea: 1-3 ft. Wire angle: 18°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
01	28.04	35.05	22.44		0.77
10	28.01	35.05	22.45		0.72
24	28.02	35.05	22.45		0.67
47	28.02	35.04	22.44		0.72
94	27.17	35.90	23.36		0.82
138	22.04	36.15	25.10		0.84
182	17.28	35.36	25.74		1.28
226	13.42	35.02	26.34		2.28
269	11.26	34.83	26.61		2.21
313	10.33	34.80	26.76		2.29
357	09.48	34.71	26.83		2.37
402	08.71	34.70	26.95		2.36
448	07.95	34.64	27.02		2.50

STATION 18

M/V Hugh M. Smith: Cruise 15, 5°26'S., 140°00'W., June 4, 1952.
Messenger time: 0424 GCT. Weather: 02, cloud coverage 9.
Wind: 090°, 10 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.03	34.95	22.37		0.59
09	27.91	34.91	22.38		0.58
22	27.80	34.94	22.44		0.60
43	27.78	34.94	22.44		0.58
85	25.98	35.73	23.61		0.78
123	20.56	35.73	25.18		1.06
161	15.40	35.21	26.06		1.91
200	12.72	34.99	26.46		2.22
241	12.05	34.96	26.57		2.17
285	11.31	34.90	26.66		2.20
330	10.45	34.82	26.75		2.52
375	09.76	34.77	26.83		2.85
421	09.08	34.76	26.94		2.85

STATION 19

M/V Hugh M. Smith: Cruise 15, 3°52'S., 140°04'W., June 4, 1952.
Messenger time: first cast 1536 GCT, second cast 1553 GCT.
Weather: 03, cloud coverage 8, Wind: 160°, 8 kt. Sea: 1-3 ft.
Wire angle: first cast 13°, second cast 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.72	35.33	22.76		0.79
10	27.69	35.35	22.78		0.82
24	27.64	35.35	22.79		0.86
48	27.60	35.31	22.78		0.80
96	15.41	35.19	26.05		2.08
144	13.04	35.01	26.41		2.48
191	12.68	1/			2.36
239	12.43	34.96	26.49		2.67
286	12.12	34.93	26.53		2.75
333	11.60	34.91	26.61		2.83
381	10.61	34.84	26.74		2.94
431	09.30	34.74	26.89		3.11
482	08.66	34.73	26.98		3.14

1/ No sample.

STATION 20

M/V Hugh M. Smith: Cruise 15, 2°50'S., 140°06'W., June 4, 1952.
Messenger time: 2353 GCT. Weather: 03, cloud coverage 7.
Wind: 070°, 10 kt. Sea: 1-3 ft. Wire angle not recorded

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.93	35.36	22.71		0.64
10	27.64	35.36	22.80		0.62
25	27.58	35.35	22.81		0.67
49	27.55	35.37	22.84		0.64
96[1]	16.76	35.31	25.82		1.66
143	12.88	34.97	26.41		2.06
190	12.52	34.94	26.46		2.29
237	12.32	34.91	26.48		2.36
283	11.91	34.90	26.55		2.59
331	11.08	34.84	26.65		2.63
378	09.88	34.77	26.81		2.83
425	08.92	34.73	26.94		2.84
474	07.94	34.67	27.04		2.89

[1] Depth in question due to erratic unprotected thermometer

STATION 21

M/V Hugh M. Smith: Cruise 15, 1°46'S., 140°09'W., June 5, 1952.
Messenger time: 0720 GCT. Weather: 02, cloud coverage 3.
Wind: 040°, 13 kt. Sea: 1-3 ft. Wire angle: 21°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.19	35.48	23.04		0.87
10	27.18	35.52	23.07		0.83
23	27.10	35.48	23.07		0.83
47	26.92	35.43	23.13		0.86
92	17.02	35.31	25.76		1.86
137	12.97	34.97	26.39		2.47
181	12.60	34.95	26.45		2.76
225	12.17	34.92	26.51		2.64
271	11.76	34.90	26.57		2.61
318	11.04	34.86	26.68		2.57
364	10.00	34.82	26.83		2.86
411	08.86	34.72	26.94		3.01
459	08.12	34.70	27.04		2.95

STATION 22

M/V *Hugh M. Smith*: Cruise 15, 0°43'S., 140°11'W., June 5, 1952.
Messenger time: 1537 GCT. Weather: 03, cloud coverage 2.
Wind: 050°, 11 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	35.49	23.30		0.69
09	26.40	35.50	23.30		0.68
22	26.39	35.51	23.32		0.72
44	26.25	35.53	23.37		0.71
88	19.99	35.61	25.24		1.27
131	15.09	35.21	26.13		1.66
174	12.64	34.97	26.46		2.12
217	12.05	34.89	26.51		2.30
260	11.81	34.88	26.55		2.23
305	11.42	34.86	26.61		2.18
350	10.76	34.82	26.70		2.26
396	09.58	34.74	26.84		2.33
451	08.17	34.66	27.00		2.63

STATION 23

M/V *Hugh M. Smith*: Cruise 15, 0°00', 139°59'W., June 5, 1952.
Messenger time: 2207 GCT. Weather: 03, cloud coverage 3.
Wind: 070°, 11 kt. Sea: 3-5 ft. Wire angle: 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	35.46	23.34		0.70
08	26.18	35.48	23.36		0.84
20	26.00	35.45	23.39		0.95
41	25.74	35.57	23.56		1.03
83 1/	22.34	35.77	24.72		1.26
126	16.92	35.27	25.76		1.49
171	13.41	35.02	26.34		1.80
215	12.52	34.95	26.47		2.09
265	11.84	34.88	26.55		2.26
311	11.12	34.83	26.64		2.29
361	10.24	34.79	26.77		2.54
408	09.02	34.73	26.92		2.70
459	08.04	34.67	27.03		3.01

1/ Depth in question due to erratic unprotected thermometer

STATION 24

M/V Hugh M. Smith: Cruise 15, 1°02'N, 139°58'W., June 6, 1952.
Messenger time: 0733 GCT. Weather: 01, cloud coverage 5.
Wind: 090°, 14 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.90	35.18	23.22		0.69
09	25.90	35.17	23.21		0.65
22	25.70	35.18	23.28		0.68
44	25.41	35.16	23.36		0.74
88	18.86	34.90	25.00		1.07
133	14.10	34.94	26.14		1.44
179	12.81	34.92	26.39		1.69
225	12.06	34.90	26.52		1.94
271	11.57	34.86	26.58		2.24
319	10.86	34.85	26.70		2.34
367	09.77	34.74	26.81		2.39
416	09.28	34.72	26.87		2.50
466	08.45	34.68	26.97		2.63

STATION 25

M/V Hugh M. Smith: Cruise 15, 2°04'N, 139°57'W., June 6, 1952.
Messenger time: 1656 GCT. Weather: 03, cloud coverage 8.
Wind: 130°, 14 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.91	35.11	22.85		0.74
09	26.90	35.10	22.85		0.75
23	26.89	35.10	22.85		0.75
44	26.61	35.09	22.93		0.81
87	19.00	34.87	24.94		1.61
127	13.10	34.81	26.24		2.13
167	12.20	34.91	26.50		2.37
207	11.92	34.89	26.54		2.47
248	11.74	34.88	26.56		2.46
289	11.45	34.87	26.61		2.49
331	10.92	34.83	26.68		2.53
375	10.24	34.78	26.76		2.48
421	09.60	34.73	26.83		2.60

STATION 26

M/V Hugh M. Smith: Cruise 15, 3°06'N., 140°00'W., June 7, 1952.
Messenger time: 0159 GCT. Weather: 02, cloud coverage 9.
Wind: 130°, 9 kt. Sea: 1-3 ft. Wire angle: 23°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O$_2$ (ml/l)	PO$_4$-P (µg at/l)
00	27.67	34.94	22.48		0.59
09	27.65	34.88	22.44		0.59
22	27.45	34.90	22.52		0.57
44	26.90	35.11	22.85		0.65
86	25.99	35.14	23.16		0.75
128	14.42	34.86	26.01		1.90
170	12.72	34.94	26.42		2.15
214	12.14	34.88	26.49		2.35
257	11.63	34.87	26.57		2.36
301	10.98	34.81	26.65		2.38
346	10.44	34.77	26.72		2.30
391	09.99	34.71	26.75		2.25
437	09.51	34.71	26.83		2.38

STATION 27

M/V Hugh M. Smith: Cruise 15, 4°09'N., 140°06'W., June 7, 1952.
Messenger time: 1109 GCT. Weather: 02, cloud coverage 9.
Wind: 140°, 11 kt. Sea: 1-3 ft. Wire angle: 25°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O$_2$ (ml/l)	PO$_4$-P (µg at/l)
00	28.04	34.66	22.15		0.58
09	28.02	1/			0.61
23	28.02	34.70	22.18		0.58
45	27.82	34.81	22.33		0.62
87	25.87	34.96	23.06		0.85
129	16.20	34.76	25.54		1.73
171	11.46	34.64	26.43		2.17
214	10.47	34.74	26.69		2.35
257	10.12	34.78	26.78		2.51
301	09.92	34.77	26.81		2.45
345	09.51	34.72	26.83		2.41
390	09.30	34.71	26.86		2.46
436	08.90	34.69	26.91		2.69

1/ No sample.

STATION 28

M/V Hugh M. Smith: Cruise 15, 5°10'N, 140°12'W., June 7, 1952.
Messenger time: 2014 GCT. Weather: 01, cloud coverage 3.
Wind: 120°, 13 kt. Sea: 1-3 ft. Wire angle: 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.81	34.13	21.82		0.35
10	27.76	34.23	21.92		0.33
25	27.84	34.58	22.15		0.38
49	27.79	34.59	22.17		0.36
97	24.67	34.92	23.40		0.66
145	13.07	34.65	26.13		1.95
193	10.49	34.71	26.66		2.51
241	09.90	34.69	26.75		2.28
289	09.53	34.70	26.82		2.60
337	09.16	34.68	26.86		2.55
385	08.88	34.67	26.90		2.66
433	08.53	34.65	26.94		2.74
482	08.21	34.64	26.98		2.78

STATION 29

M/V Hugh M. Smith: Cruise 15, 6°07'N, 140°11'W., June 8, 1952.
Messenger time: 0340 GCT. Weather: 65, cloud coverage 10.
Wind: 120°, 12 kt. Sea: 1-3 ft. Wire angle: 04°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	28.05	34.46	22.00		0.57
12	27.88	34.48	22.07		0.60
27	27.80	34.56	22.15		0.52
52	27.66	34.61	22.24		0.58
101	17.45	34.71	25.20		1.31
150	11.80	34.68	26.40		2.57
199	10.42	34.70	26.66		2.73
247	09.81	34.69	26.76		2.65
295	09.40	34.66	26.81		2.68
344	09.05	34.66	26.86		2.73
394	08.77	34.64	26.89		2.81
443	08.32	34.62	26.95		2.88
493	08.01	34.61	26.99		2.96

STATION 30

M/V Hugh M. Smith: Cruise 15, 7°04'N., 140°10'W., June 8, 1952.
Messenger time: 1224 GCT. Weather: 51, cloud coverage 8.
Wind: 060°, 10 kt. Sea: 1-3 ft. Wire angle: 03°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	27.34	34.50	22.25		0.37
12	27.36	34.52	22.26		0.36
27	27.26	34.64	22.39		0.38
51	27.11	34.72	22.50		0.32
100	12.34	34.71	26.32		2.60
148	10.96	34.71	26.58		2.57
196	10.25	34.71	26.70		2.58
244	09.64	34.69	26.79		2.59
293	09.22	34.68	26.85		2.70
341	08.86	34.64	26.88		2.71
389	08.45	34.63	26.93		2.80
439	08.06	34.61	26.98		2.84
490	07.62	34.59	27.03		2.86

STATION 31

M/V Hugh M. Smith: Cruise 15, 8°00'N., 140°00'W., June 8, 1952.
Messenger time: 1941 GCT. Weather: 02, cloud coverage 4.
Wind: 090°, 12 kt. Sea: 3-5 ft. Wire angle: 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
01	27.15	34.53	22.34		0.63
11	26.96	34.53	22.40		0.59
24	26.83	34.52	22.42		0.62
48	14.67	34.53	25.70		2.72
97	11.94	34.78	26.45		2.98
144	11.14	34.74	26.57		3.08
191	10.53	34.73	26.67		2.94
237	10.04	34.71	26.74		2.93
285	09.70	34.69	26.78		3.00
333	09.37	34.69	26.84		3.22
381	08.90	34.64	26.87		3.39
430	08.48	34.61	26.91		3.38
480	07.97	34.60	26.99		3.45

STATION 32

M/V Hugh M. Smith: Cruise 15, 7°04'N., 140°04'W., June 9, 1952.
Messenger time: 0357 GCT. Weather: 03, cloud coverage 6.
Wind: 090°, 11 kt. Sea: 5-8 ft. Wire angle: 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.65	34.55	22.19		0.35
10	27.59	34.56	22.22		0.34
24	27.24	34.71	22.44		0.39
48	26.74	34.90	22.75		0.53
96	12.46	34.69	26.28		2.68
191	10.06	34.69	26.72		2.53
239	09.56	34.69	26.80		2.64
287	09.18	34.66	26.84		2.65
336	08.86	34.65	26.90		2.72
382	08.57	34.64	26.92		2.72
430	08.10	34.62	26.98		2.81
479	07.70	34.61	27.03		2.90

150 meter bottle pretripped.

STATION 33

M/V Hugh M. Smith: Cruise 15, 6°05'N., 139°58'W., June 9, 1952.
Messenger time: 1421 GCT. Weather: 01, cloud coverage 6.
Wind: 200° (variable), 4 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.83	34.39	22.01		0.55
09	27.85	34.46	22.06		0.55
22	27.84	34.47	22.07		0.59
42	27.84	34.47	22.07		0.61
81	24.61	34.96	23.37		0.79
117	14.10	34.59	25.87		1.92
155	11.20	34.71	26.53		2.59
192	10.37	34.70	26.67		2.74
231	09.92	34.70	26.75		2.68
271	09.52	34.68	26.80		2.68
312[1]	09.24	34.69	26.81		2.73
355	08.92	34.65	26.88		2.84
400	08.68	34.61	26.88		2.88

[1] Depth in question due to erratic unprotected thermometer.

STATION 34

M/V Hugh M. Smith: Cruise 15, 5°00'N., 139°51'W., June 10, 1952.
Messenger time: 0101 GCT. Weather: 02, cloud coverage 7.
Wind: 180°, 7 kt. Sea: 1-3 ft. Wire angle: 22°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.25	34.51	21.93		0.41
10	28.14	34.52	22.01		0.39
23	28.05	34.52	22.04		0.42
47	27.72	34.79	22.35		0.57
93	25.25	34.96	23.25		0.77
139	14.84	34.68	25.78		1.74
184	11.44	34.63	26.43		2.25
229	10.10	34.67	26.70		2.39
274	09.78	34.70	26.77		2.26
319	09.43	34.69	26.83		2.38
365	09.06	34.64	26.85		2.71
410	08.68	34.65	26.92		2.70
456	08.32	34.62	26.95		2.74

STATION 35

M/V Hugh M. Smith: Cruise 15, 4°01'N., 139°55'W., June 10, 1952.
Messenger time: 1004 GCT. Weather: 02, cloud coverage 1.
Wind: 110°, 9 kt. Sea: 1-3 ft. Wire angle: 38°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.42	34.83	22.48		0.68
08	27.42	34.81	22.46		0.61
19	27.14	34.95	22.66		0.65
37	27.02	35.00	22.74		0.70
70	27.04	35.01	22.73		0.75
102 1/	27.18	34.99	22.67		0.73
137	13.00	34.93	26.35		2.29
173	12.28	34.92	26.49		2.40
211	11.54	34.85	26.57		2.25
250	11.67	34.81	26.52		2.28
288	10.58	34.77	26.69		2.33
328	10.09	34.75	26.76		2.59
368	09.79	34.71	26.78		2.42

1/ Suspected pretrip.

STATION 36

M/V *Hugh M. Smith*: Cruise 15, 3°00'N., 139°57'W., June 10, 1952.
Messenger time: 1825 GCT. Weather: 02, cloud coverage 3.
Wind: 140°, 8 kt. Sea: 1-3 ft. Wire angle: 47°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.98	34.87	22.65		0.56
06	26.92	34.91	22.70		0.55
16	26.86	34.94	22.74		0.61
32	26.50	35.02	22.91		0.62
58	26.47	35.00	22.91		0.64
80	23.69	34.95	23.72		0.90
97	16.06	34.87	25.65		1.80
118	14.03	34.94	26.15		2.00
139	13.14	34.93	26.33		2.04
161	12.70	34.95	26.42		2.14
184	12.57	34.94	26.45		2.14
210	12.19	34.88	26.48		2.21
235	11.83	34.88	26.55		2.29

STATION 37

M/V *Hugh M. Smith*: Cruise 15, 2°00'N., 139°56'W., June 11, 1952.
Messenger time: 0254 GCT. Weather: 03, cloud coverage 7.
Wind: 120°, 10 kt. Sea: 3-5 ft. Wire angle: 32°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.05	34.97	22.70		0.73
08	26.88	35.00	22.78		0.73
21	26.72	35.05	22.87		0.73
42	26.28	35.05	23.00		0.78
81	22.64	34.90	23.98		1.21
120	13.80	34.75	26.05		1.99
157	12.47	34.87	26.41		2.32
196	12.10	34.87	26.49		2.54
235	11.77	34.86	26.54		2.48
275	11.44	34.85	26.59		2.57
315	10.84	34.78	26.65		2.62
357	10.35	34.78	26.74		2.67
400	09.76	34.70	26.78		2.70

STATION 38

M/V Hugh M. Smith: Cruise 15, 0°58'N., 139°56'W., June 11, 1952.
Messenger time: 1132 GCT. Weather: 03, cloud coverage 2.
Wind: 100°, 11 kt. Sea: 3-5 ft. Wire angle: 36°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.48	35.12	22.99		0.66
08	26.46	35.13	23.01		0.64
20	26.44	35.10	22.99		0.63
39	26.36	35.09	23.01		0.61
78	20.45	34.90	24.56		1.04
159	11.95	34.80	26.46		1.88
199	11.74	34.87	26.55		2.04
243	11.52	34.85	26.58		2.21
331	10.33	34.74	26.71		2.25
377	09.89	34.71	26.76		2.31
424	08.41	34.66	26.96		2.74

120 and 300 meter bottles pretripped.

STATION 39

M/V Hugh M. Smith: Cruise 15, 0°04'S., 139°54'W., June 11, 1952.
Messenger time: 2029 GCT. Weather: 01, cloud coverage 1.
Wind: 110°, 13 kt. Sea: 3-5 ft. Wire angle: 33°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.92	35.15	23.19		0.80
09	25.84	35.15	23.22		0.74
21	25.64	35.15	23.28		0.76
44	24.90	35.27	23.60		0.85
88	19.84	35.29	25.04		1.21
134	14.10	34.97	26.16		1.56
181	12.46	34.93	26.46		1.92
229	12.05	34.88	26.50		2.09
277	11.70	34.86	26.55		2.37
373	09.82	34.73	26.79		2.67
422	08.95	34.70	26.91		2.86
471	08.16	34.63	26.98		3.00

300 meter bottle pretripped.

STATION 40

M/V Hugh M. Smith: Cruise 15, 1°06'S., 139°51'W., June 12, 1952. Messenger time: 0614 GCT. Weather: 02, cloud coverage 5. Wind: 130°, 12 kt. Sea: 3-5 ft. Wire angle: 18°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.08	35.46	23.38		0.75
09	26.06	35.45	23.38		0.73
23	25.90	35.47	23.44		0.76
47	25.81	35.51	23.50		0.75
95	20.20	35.71	25.27		1.21
190	12.98	35.02	26.43		1.99
238	11.92	34.90	26.54		2.13
285	11.72	34.88	26.57		2.26
333	11.28	34.86	26.63		2.27
381	09.78	34.77	26.83		2.40
430	08.51	34.66	26.95		2.60
479	07.88	34.63	27.02		2.74

150 meter bottle pretripped.

STATION 41

M/V Hugh M. Smith: Cruise 15, 2°08'S., 139°50'W., June 12, 1952. Messenger time: 1459 GCT. Weather: 02, cloud coverage 8. Wind: 140°, 9 kt. Sea: 3-5 ft. Wire angle: 07°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	26.59	35.46	23.22		0.72
12	26.57	35.44	23.21		0.72
26	26.56	35.44	23.21		0.72
50	26.53	35.46	23.24		0.74
98	17.30	35.25	25.65		1.75
146	13.09	34.92	26.33		2.39
194	12.67	34.90	26.40		2.31
241	12.31	34.88	26.45		2.46
289	11.78	34.87	26.55		2.63
337	10.89	34.82	26.67		2.77
384	09.68	34.73	26.81		2.79
432	08.66	34.65	26.92		2.74
480	07.97	34.64	27.02		2.89

STATION 42

M/V Hugh M. Smith: Cruise 15, 3°13'S., 139°49'W., June 12, 1952.
Messenger time: 2205 GCT. Weather: 03, cloud coverage 3.
Wind: 130°, 9 kt. Sea: 5-8 ft. Wire angle: 04°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	27.32	35.41	22.94		0.70
12	27.28	35.42	22.97		0.71
27	27.19	35.43	23.00		0.69
52	27.19	35.43	23.00		0.69
100	17.64	35.35	25.64		1.43
149	13.10	34.96	26.36		2.07
198	12.64	34.90	26.40		2.17
247	12.32	34.88	26.45		2.34
296	11.96	34.87	26.52		2.56
344	11.34	34.83	26.60		2.68
393	10.18	34.74	26.74		2.75
442	09.10	34.70	26.89		2.73
492	08.12	34.63	26.98		2.78

STATION 43

M/V Hugh M. Smith: Cruise 15, 4°05'S., 139°49'W., June 13, 1952.
Messenger time: 0529 GCT. Weather: 02, cloud coverage 4.
Wind: 110°, 11 kt. Sea: 5-8 ft. Wire angle: 16°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.40	35.42	22.93		0.70
10	27.38	35.43	22.94		0.72
24	27.30	35.44	22.97		0.71
48	27.30	35.43	22.97		0.73
95	23.90	35.62	24.16		1.13
142	13.57	34.99	26.29		2.36
189	12.56	34.90	26.42		2.43
234	12.22	34.87	26.46		2.58
280	11.78	34.84	26.52		2.73
327	11.21	34.82	26.61		2.59
374	09.98	34.73	26.76		2.81
420	09.12	34.68	26.87		2.92
469	08.52	34.65	27.21		2.81

STATION 44

M/V Hugh M. Smith: Cruise 15, 5°32'S., 139°54'W., June 13, 1952.
Messenger time: first cast 1803 GCT, second cast 1815 GCT.
Weather: 01, cloud coverage 6. Wind: 130°, 18 kt. Sea: 5-8 ft.
Wire angle: first cast 25°, second cast 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/1)	O_2 (ml/1)	PO_4-P (µg at/1)
00	27.54	35.09	22.63		0.67
08	27.54	35.10	22.64		0.65
22	27.52	35.11	22.65		0.63
44	27.52	35.14	22.68		0.64
88	25.82	35.70	23.64		0.76
134	19.81	35.64	25.32		1.05
178	13.87	35.00	26.23		2.11
223	12.08	34.88	26.50		2.60
267	11.34	34.84	26.60		2.57
312	10.74	34.79	26.68		2.62
357	09.98	34.73	26.76		2.75
402	09.34	34.69	26.84		2.80
447	08.83	34.64	26.88		2.86

STATION 45

M/V Hugh M. Smith: Cruise 15, 7°00'S., 140°00'W., June 14, 1952.
Messenger time: 0657 GCT. Weather: 64, cloud coverage 10.
Wind: 120°, 18 kt. Sea: 5-8 ft. Wire angle: 26°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/1)	O_2 (ml/1)	PO_4-P (µg at/1)
00	27.71	34.95	22.47		0.70
09	27.70	34.97	22.49		0.68
22	27.68	34.96	22.49		0.70
43	27.71	34.96	22.48		0.71
86	27.36	35.87	23.28		0.76
127	24.36	36.20	24.46		0.81
169	20.33	35.74	25.25		1.05
210	16.91	35.22	25.72		1.42
251	12.74	34.78	26.29		2.12
292	11.10	34.77	26.60		2.51
335	09.86	34.73	26.73		2.48
375	09.09	34.63	26.87		2.62
417	08.55	34.66	26.94		2.61

STATION 46

M/V Hugh M. Smith: Cruise 15, 5°29'S., 140°05'W., June 15, 1952.
Messenger time: first cast 0010 GCT, second cast 0047 GCT.
Weather: 01, cloud coverage 2. Wind: 080°, 13 kt. Sea: 5-8 ft.
Wire angle: first cast 39°, second cast 48°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.61	35.26	22.74		0.71
08	27.60	35.26	22.74		0.71
20	27.52	35.25	22.76		0.70
37	27.50	35.27	22.78		0.70
71	27.30	35.35	22.91		0.69
103	24.00	35.88	24.33		0.89
137	19.18	35.57	25.43		1.10
171	14.86	35.12	26.11		1.95
207	13.42	35.00	26.33		2.15
236[1]	12.46	34.93	26.46		2.50
283	11.44	34.84	26.59		2.48
323	10.89	34.82	26.67		2.44
364	09.92	34.75	26.79		2.65

[1] Bottle pretripped and was sent down again as a second cast.

STATION 47

M/V Hugh M. Smith: Cruise 15, 3°43'S., 140°04'W., June 15, 1952.
Messenger time: 1621 GCT. Weather: 01, cloud coverage 6.
Wind: 080°, 11 kt. Sea: 3-5 ft. Wire angle: 23°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.29	35.39	22.94		0.71
09	27.26	35.38	22.94		0.71
23	27.25	35.38	22.94		0.69
45	27.24	35.37	22.94		0.70
90	22.08	35.43	24.54		1.30
133	13.37	34.95	26.30		2.33
175	12.78	34.90	26.38		2.37
218	12.44	34.87	26.42		2.39
260	12.15	34.87	26.48		2.35
302	11.82	34.88	26.55		2.68
346	11.30	34.81	26.59		2.77
389	10.31	34.77	26.74		2.82
433	09.24	34.67	26.84		2.94

STATION 48

M/V Hugh M. Smith: Cruise 15, 3°00'S., 140°00'W., June 15, 1952. Messenger time: 2340 GCT. Weather: 02, cloud coverage 1. Wind: 120°, 11 kt. Sea: 3-5 ft. Wire angle: 27°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.14	35.47	23.05		0.73
09	27.04	35.46	23.07		0.73
22	26.90	35.45	23.11		0.72
44	26.88	35.46	23.12		0.72
87	22.16	35.44	24.52		1.23
129	13.86	34.99	26.23		2.19
171	12.86	34.89	26.35		2.35
213	12.53	34.88	26.41		2.40
256	12.14	34.86	26.47		2.48
298	11.69	34.82	26.53		2.50
341	10.85	34.78	26.65		2.75
384	10.25	34.75	26.73		2.74
428	09.03	34.66	26.87		2.77

STATION 49

M/V Hugh M. Smith: Cruise 15, 2°00'S., 139°53'W., June 16, 1952. Messenger time: 0914 GCT. Weather: 02, cloud coverage 1. Wind: 100°, 12 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.57	35.53	23.27		0.81
09	26.57	35.55	23.29		0.79
23	26.54	35.55	23.30		0.78
46	26.46	35.54	23.32		0.76
92	22.12	35.63	24.68		1.16
136	13.90	35.05	26.26		2.21
181	12.71	34.96	26.44		2.20
226	12.28	34.93	26.50		2.32
272	11.90	34.91	26.56		2.35
319	11.48	34.87	26.60		2.35
366	11.04	34.84	26.66		2.25
413	09.72	34.78	26.85		2.71
463	08.26	34.66	26.99		2.73

STATION 50

M/V Hugh M. Smith: Cruise 15, 0°57'S., 139°47'W., June 16, 1952.
Messenger time: 1834 GCT. Weather: 02, cloud coverage 1.
Wind: 090°, 11 kt. Sea: 3-5 ft. Wire angle: 25°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.94	35.45	23.41		0.76
09	25.90	35.43	23.41		0.76
23	25.82	35.44	23.44		0.78
45	25.63	35.47	23.52		0.79
91	21.36	35.77	25.00		1.16
186	13.07	34.96	26.37		1.72
233	12.06	34.91	26.53		2.05
281	11.68	34.87	26.57		2.33
330	10.20	34.77	26.76		2.35
378	09.15	34.69	26.87		2.57
427	08.46	34.67	26.96		2.69
476	07.72	34.62	27.04		2.87

150 meter bottle pretripped.

STATION 51

M/V Hugh M. Smith: Cruise 15, 0°01'S., 139°43'W., June 17, 1952.
Messenger time: 0119 GCT. Weather: 03, cloud coverage 2.
Wind: 100°, 9 kt. Sea: 3-5 ft. Wire angle: 46°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.94	35.26	23.27		0.78
06	25.87	35.26	23.29		0.76
17	25.44	35.25	23.41		0.76
34	25.08	35.28	23.55		0.77
72	21.34	35.24	24.60		1.08
153	13.88	34.92	26.17		1.53
198	12.40	34.88	26.44		1.84
244	11.98	34.85	26.50		2.04
290	11.46	34.81	26.56		2.35
337	10.40	34.73	26.69		2.34
385	09.76	34.71	26.79		2.51
435	08.88	34.65	26.88		2.64

120 meter bottle pretripped.

STATION 52

M/V Hugh M. Smith: Cruise 15, 1°00'N., 139°51'W., June 17, 1952.
Messenger time: 1013 GCT. Weather: 02, cloud coverage 2.
Wind: 100°, 11 kt. Sea: 3-5 ft. Wire angle: 17°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.80	35.08	23.18		0.75
10	25.81	35.03	23.14		0.75
24	25.66	35.05	23.18		0.75
48	24.22	34.97	23.57		0.95
96	17.63	34.79	25.22		1.32
190	11.72	34.85	26.54		2.07
236	11.62	34.86	26.57		2.25
283	11.26	34.81	26.60		2.33
331	10.82	34.83	26.69		2.35
377	09.70	34.69	26.78		2.36
426	08.56	34.67	26.95		2.68
474	07.99	34.63	27.01		2.78

150 meter bottle pretripped.

STATION 53

M/V Hugh M. Smith: Cruise 15, 2°06'N., 140°02'W., June 17, 1952.
Messenger time: 1951 GCT. Weather: 02, cloud coverage 2.
Wind: 110°, 11 kt. Sea: 3-5 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.69	34.95	22.80		0.66
08	26.65	34.96	22.82		0.66
19	26.57	34.93	22.82		0.66
35	26.42	34.96	22.89		0.73
68	25.70	35.10	23.22		0.74
94	22.28	34.90	24.08		1.16
121	13.54	34.96	26.27		2.26
148	12.88	34.92	26.37		2.30
175	12.49	34.88	26.42		2.31
203	12.18	34.87	26.47		2.44
230	11.84	34.85	26.52		2.50
262	11.50	34.82	26.56		2.46
299	11.12	34.79	26.61		2.52

STATION 54

M/V Hugh M. Smith: Cruise 15, 3°11'N, 140°13'W., June 18, 1952.
Messenger time: 0420 GCT. Weather: 03, cloud coverage 2.
Wind: 140°, 13 kt. Sea: 3-5 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.92	34.67	22.19		0.48
08	27.94	34.67	22.19		0.48
21	27.90	34.67	22.20		0.48
36	27.83	34.68	22.23		0.52
69	27.41	34.82	22.48		0.58
100	25.62	34.93	23.12		0.81
127	13.86	34.95	26.19		2.13
155	13.07	34.94	26.35		2.15
185	12.74	34.92	26.40		2.18
216	12.35	34.89	26.45		2.26
249	12.04	34.87	26.50		2.33
283	11.58	34.83	26.55		2.36
320	11.00	34.79	26.63		2.35

STATION 55

M/V Hugh M. Smith: Cruise 15, 4°00'N, 140°09'W., June 18, 1952.
Messenger time: 1156 GCT. Weather: 02, cloud coverage 1.
Wind: 120°, 12 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.92	34.63	22.16		0.52
09	27.94	34.64	22.17		0.52
21	27.92	34.62	22.16		0.52
41	27.92	34.64	22.17		0.53
65 1/	27.89	34.70	22.23		0.66
79	27.28	34.84	22.53		0.69
158	12.99	34.91	26.34		2.21
197	12.14	34.88	26.49		2.43
240	11.60	34.83	26.55		2.46
283	10.96	34.79	26.64		2.44
327	10.39	34.77	26.73		2.47
372	10.02	34.73	26.76		2.39
419	09.50	34.71	26.83		2.47

1/ Suspected pretrip.

STATION 56

M/V Hugh M. Smith: Cruise 15, 5°00'N., 140°04'W., June 18, 1952.
Messenger time: 1922 GCT. Weather: 02, cloud coverage 6.
Wind: 130°, 10 kt. Sea: 3-5 ft. Wire angle: 04°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O2 (ml/l)	PO4-P (µg at/l)
02	27.98	34.65	22.16		0.49
12	27.84	34.66	22.21		0.51
27	27.82	34.64	22.20		0.45
52	27.82	34.64	22.20		0.46
101	27.50	34.92	22.52		0.64
197	10.92	34.71	26.58		2.09
245	10.43	34.73	26.69		2.44
293	10.00	34.73	26.76		2.44
342	09.62	34.70	26.80		2.50
390	09.28	34.66	26.83		2.52
439	08.94	34.61	26.84		2.53
487	08.62	34.65	26.92		2.68

150 meter bottle pretripped.

STATION 57

M/V Hugh M. Smith: Cruise 15, 5°54'N., 140°00'W., June 19, 1952.
Messenger time: 0242 GCT. Weather: 02, cloud coverage 9.
Wind: 010°, 4 kt. Sea: 3-5 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O2 (ml/l)	PO4-P (µg at/l)
00	28.17	34.39	21.90		0.46
10	27.96	34.42	21.99		0.48
24	27.98	34.73	22.22		0.55
48	27.93	34.78	22.27		0.66
95	25.98	34.91	22.99		0.78
141 1/	19.20	34.71	24.76		1.44
186	10.94	34.70	26.57		2.68
230	10.12	34.69	26.71		2.69
275	09.62	34.69	26.79		2.62
321	09.28	34.67	26.83		2.79
367	08.90	34.66	26.89		2.83
415	08.57	34.65	26.93		2.80
465	08.17	34.61	26.96		2.96

1/ Temperature value not in agreement with the BT, omitted from T-S curve.

STATION 58

M/V Hugh M. Smith: Cruise 15, 6°47'N, 139°56'W., June 19, 1952.
Messenger time: 1250 GCT. Weather: 02, cloud coverage 2.
Wind: 040°, 19 kt. Sea: 5-8 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.77	34.70	22.27		0.44
10	27.75	34.66	22.24		0.46
25	27.75	34.70	22.27		0.44
49	27.56	34.73	22.36		0.45
97	13.60	34.61	25.99		1.88
145	11.28	34.72	26.52		2.51
192	10.12	34.72	26.73		2.48
240	09.70	34.76	26.83		2.63
288	09.38	34.70	26.84		2.63
336	09.09	34.69	26.88		2.64
384	08.84	34.68	26.91		2.72
432	08.44	34.66	26.96		2.73
482	08.10	34.64	27.00		2.81

STATION 59

M/V Hugh M. Smith: Cruise 15, 8°00'N, 139°52'W., June 19, 1952.
Messenger time: 2316 GCT. Weather: 02, cloud coverage 2.
Wind: 040°, 11 kt. Sea: 5-8 ft. Wire angle: 03°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	27.29	34.40	22.20		0.50
12	27.18	34.43	22.25		0.54
27	27.10	34.83	22.58		0.56
52	13.84	34.52	25.87		2.36
101	11.92	34.79	26.46		2.88
150	10.92	34.71	26.58		2.83
198	10.15	34.68	26.70		2.80
246	09.70	34.69	26.78		2.85
294	09.36	34.63	26.79		2.88
342	08.98	34.64	26.86		2.94
391	08.58	34.62	26.91		3.05
439	08.18	34.60	26.95		3.12
488	07.74	34.59	27.01		3.24

STATION 60

M/V Hugh M. Smith: Cruise 15, 9°00'N, 140°00'W., June 20, 1952.
Messenger time: 0741 GCT. Weather: 02, cloud coverage 3.
Wind: 040°, 13 kt. Sea: 5-8 ft. Wire angle: 02°

OBSERVED

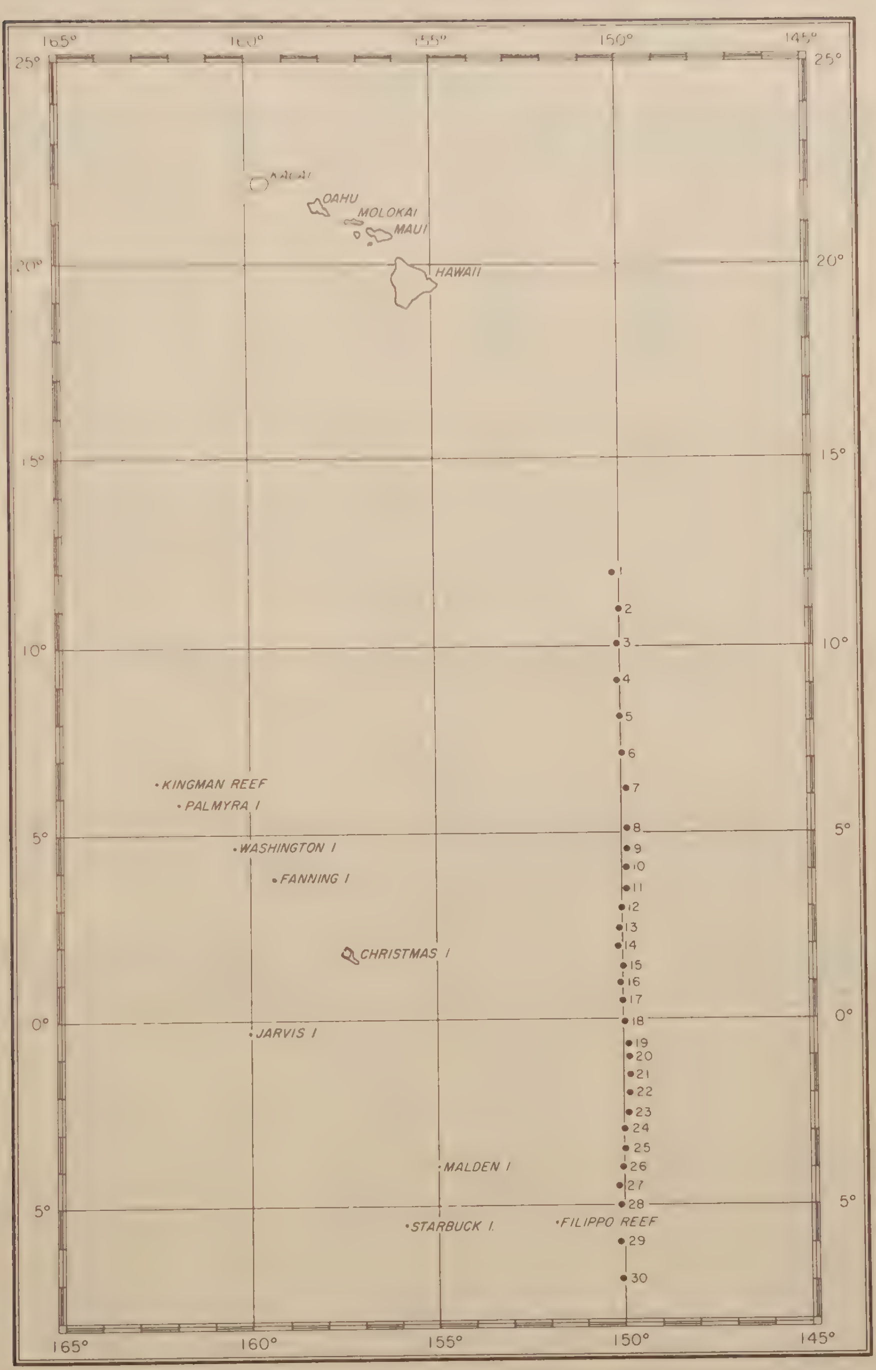
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	27.09	34.45	22.30		0.35
12	27.08	34.47	22.32		0.35
27	27.04	34.46	22.32		0.35
51	13.72	34.65	25.99		2.56
99	11.67	34.77	26.49		2.57
147	10.94	34.73	26.59		2.55
195	10.44	34.72	26.68		2.59
243	10.12	34.70	26.72		2.67
292	09.75	34.67	26.74		2.75
340	09.32	34.67	26.83		2.86
388	08.82	34.61	26.86		2.91
438	08.31	34.61	26.94		3.01
488	07.90	34.57	26.97		3.10

Notes on the tabulated data, Hugh M. Smith cruise 16

1. All stations of this cruise consisted of shallow casts, with the bottle spacing varied to give maximum detail in the region of the thermocline. Any variation from a 13-bottle cast has been explained in a footnote.

2. On all stations, when the corrected readings of the duplicate protected thermometers differed by more than 0.1° above 300 M, or 0.05° below 300 M, the depth of observation is repeated and both temperatures are carried. Sigma-t values calculated using each temperature are tabulated. Similarly, when the duplicate determinations of inorganic phosphate for any depth differed by more than 0.01 extinction (approximately 0.04 µg at/l), the depth of observation is repeated, and both values are carried. However, when one of either of the above duplicates was known definitely to be in error, it was dropped from the tabulations.

3. Weather is recorded according to the ww (present weather) code in the U. S. Weather Bureau Circular M, 8th edition, Manual of Marine Meteorological Observations. Wind velocity was measured with an anemometer 30 M above the sea surface; speed is recorded in knots, and direction is given in degrees true from which the wind was blowing.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HAWAII
KINGMAN REEF
PALMYRA I
WASHINGTON I
FANNING I
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JARVIS I
MALDEN I
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Appendix A, Fig. 1. -- Station positions for Hugh M. Smith cruise 16, July 23 to August 29, 1952.

STATION 1

M/V Hugh M. Smith: Cruise 16, 11°56'N., 150°09'W., July 27, 1952. Messenger time: 1425 GCT. Weather: 02, cloud coverage not recorded. Wind: 060°, 22 kt. Sea: 3-5 ft. Wire angle: 41°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.12	34.64	22.75		0.29
37	25.96	34.71	22.85		0.32
55	25.37	34.69	23.02		0.36
73	24.06	34.64	23.37		0.35
91	22.20	34.95	24.14		0.34
108	20.02	34.78	24.61		0.45
127	15.95	34.43	25.34		1.14
127					1.18
144	13.56	34.51	25.92		2.40
161	12.63	34.63	26.20		2.68
179	12.06	34.74	26.40		2.68
216	11.45	34.76	26.52		2.60
255	11.04	34.70	26.55		2.62
255					2.67
295	10.70	34.73	26.64		2.64
295 1/	10.62	34.73	26.65		2.56

1/ Both the temperature and phosphate determinations were out of tolerance for this depth.

STATION 2

M/V Hugh M. Smith: Cruise 16, 11°00'N., 150°00'W., July 27, 1952. Messenger time: 2306 GCT. Weather: 81, cloud coverage 10. Wind: 070°, 23 kt. Sea: 5-8 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.29	1/			0.39
44	25.72	34.77	22.97		0.41
66	25.17	34.70	23.09		0.36
87	22.34	34.89	24.06		0.36
109	19.62	34.79	24.72		0.59
131	16.18	34.45	25.30		1.20
153	13.34	34.52	25.97		2.34
175	12.63	1/			2.64
198	11.94	34.73	26.41		2.69
220	11.44	1/			2.31
220					2.40 2/
264	10.87	34.76	26.63		2.66
310	10.36	34.70	26.67		2.67
356	09.92	34.71	26.76		2.66
356	09.86	34.71	26.77		2.61

1/ No samples.

2/ Both values appear anomalous.

STATION 3

M/V Hugh M. Smith: Cruise 16, 10°01'N, 150°03'W., July 28, 1952. Messenger time: 0807 GCT. Weather: 02, cloud coverage not recorded. Wind: 070°, 10 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.37	34.25	22.05		0.42
41	25.64	34.70	22.94		0.43
62	24.58	34.63	23.21		0.38
82	21.54	34.89	24.28		0.43
103	17.67	34.54	25.02		1.03
123	14.02	34.39	25.72		2.07
143	13.01	34.65	26.14		2.63
164	12.31	34.71	26.32		2.80
184	11.66	34.70	26.44		2.71
184					2.80
204	11.34	34.70	26.50		2.77
204					2.84
245	10.82	34.70	26.59		2.81
288	10.30	34.68	26.67		2.81
332	09.82	34.67	26.74		2.88
332					2.83

STATION 4

M/V Hugh M. Smith: Cruise 16, 9°05'N, 150°06'W., July 28, 1952. Messenger time: 1653 GCT. Weather: 02, cloud coverage 7. Wind: 160°, 16 kt. Sea: 3-5 ft. Wire angle: 16°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.74	34.42	22.06		0.37
47	25.85	34.66	22.84		0.37
71	21.80	34.60	23.99		0.43
94	15.96	34.38	25.30		1.08
94					1.02
117	12.98	34.49	26.02		2.44
140	12.00	34.60	26.30		2.66
163	11.46	34.69	26.47		2.56
184	11.11	34.74	26.57		2.66
207	10.72	34.72	26.63		2.66
229	10.40	34.70	26.67		2.66
275	09.82	34.66	26.74		2.69
321	09.38	34.62	26.78		2.83
321					2.73
368 1/	09.36	34.60	26.76		2.73
368	09.49	34.60	26.74		

1/ Suspected pretrip.

STATION 5

M/V *Hugh M. Smith*: Cruise 16, 8°06'N., 150°02'W., July 29, 1952. Messenger time: 0135 GCT. Weather: 02, cloud coverage 5. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: 01°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	28.19	34.48	21.96		0.41
45	27.72	34.68	22.27		0.39
65	24.77	34.68	23.19		0.50
85	16.76	34.44	25.16		1.24
104	12.82	34.46	26.03		2.35
104					2.31
124	12.15	34.71	26.35		2.74
148	11.57	34.77	26.51		2.68
148					2.60
172	11.14	34.76	26.58		2.72
196	10.76	34.76	26.65		2.69
196					2.59
243	10.24	34.74	26.73		2.69
291	09.78	34.74	26.80		2.75
340	09.42	34.70	26.83		2.73
340					2.78
389	08.96	34.68	26.89		2.79

STATION 6

M/V *Hugh M. Smith*: Cruise 16, 7°08'N., 149°58'W., July 29, 1952. Messenger time: 1052 GCT. Weather: 81, cloud coverage not recorded. Wind: 090°, 17 kt. Sea: 3-5 ft. Wire angle: 00°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	28.16	34.86	22.26		0.48
45	28.20	34.91	22.28		0.49
65	28.20	34.91	22.28		0.46
84	28.08	34.89	22.31		0.51
84					0.46
104	23.15	34.74	23.72		0.81
123	17.70	34.54	25.01		1.12
147	13.06	34.47	25.99		2.22
172	11.52	34.65	26.42		2.65
196	10.86	34.70	26.58		2.63
244	10.08	34.70	26.72		2.72
244					2.67
291	09.58	34.70	26.81		2.65
340	09.09	34.66	26.86		2.69
340					2.63
388	08.72	34.63	26.89		2.77
388					2.71

STATION 7

M/V Hugh M. Smith: Cruise 16, 6°10'N, 149°49'W., July 29, 1952.
Messenger time: 1943 GCT. Weather: 02, cloud coverage 10.
Wind: 130°, 20 kt. Sea: 5-8 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.94	34.95	22.40		0.50
59	27.80	35.00	22.48		0.55
59					0.59
77	26.98	35.15	22.86		0.60
92	26.65	35.15	22.96		0.65
106	26.42	35.15	23.04		0.70
119	25.54	35.02	23.21		0.87
138	22.60	34.87	23.97		0.91
161	16.42	34.67	25.42		1.41
183	13.40	34.62	26.04		1.99
229	11.02	34.71	26.57		2.73
275	09.82	34.71	26.77		2.67
321	09.28	34.67	26.83		2.63
368	08.96	34.64	26.86		2.68
368					2.60

STATION 8

M/V Hugh M. Smith: Cruise 16, 5°06'N, 149°51'W., July 30, 1952.
Messenger time: 0511 GCT. Weather: 02, cloud coverage 5.
Wind: 120°, 18 kt. Sea: 5-8 ft. Wire angle: 06°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.53	34.87	22.47		0.55
58	27.46	34.88	22.50		0.55
97	27.10	35.05	22.74		0.54
116	27.08	35.03	22.74		0.62
135	25.76	34.95	23.09		0.81
154	20.44	34.83	24.53		1.25
173	15.13	34.68	25.72		1.64
173					1.59
196	12.30	34.60	26.24		2.09
221	10.59	34.64	26.59		2.28
246	09.89	34.66	26.72		2.42
246					2.49
293	09.28	34.66	26.83		2.47
343	09.00	34.69	26.70		2.47
392	08.78	34.66	26.91		2.46

STATION 9

M/V Hugh M. Smith: Cruise 16, 4°34'N, 149°51'W., July 30, 1952. Messenger time: 1104 GCT. Weather: 02, cloud coverage not recorded. Wind: 110°, 16 kt. Sea: 5-8 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.60	34.82	22.41		0.57
60	27.59	34.81	22.41		0.57
97	27.21	34.88	22.58		0.61
116	26.80	34.90	22.73		0.79
135	24.88	34.92	23.34		0.97
153	18.42	34.76	25.00		1.34
173	14.54	34.64	25.81		1.78
192	12.80	34.61	26.15		2.05
192					1.99
215	10.96	34.62	26.51		2.17
239	09.97	34.68	26.73		2.36
287	09.39	34.70	26.84		2.48
335	09.27	34.69	26.85		2.52
385	08.88	34.69	26.92		2.59

STATION 10

M/V Hugh M. Smith: Cruise 16, 4°02'N, 149°52'W., July 30, 1952. Messenger time: 1658 GCT. Weather: 02, cloud coverage 1. Wind: 120°, 17 kt. Sea: 5-8 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.60	34.80	22.40		0.51
52	27.61	34.80	22.39		0.54
52					0.50
86	27.38	34.84	22.50		0.53
102	26.70	34.85	22.72		0.73
119	25.68	34.88	23.06		0.81
135	22.62	34.88	23.97		1.11
152	15.26	34.67	25.68		1.56
169	14.48	34.65	25.83		1.70
189	12.20	34.60	26.26		1.87
210	10.96	34.65	26.53		2.01
251	10.04	34.70	26.73		2.27
294	09.76	34.71	26.78		2.37
336	09.50	34.69	26.81		2.40

STATION 11

M/V Hugh M. Smith: Cruise 16, 3°32'N., 149°53'W., July 30, 1952.
Messenger time: 2240 GCT. Weather: 02, cloud coverage 2.
Wind: 100°, 19 kt. Sea: 5-8 ft. Wire angle: 40°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	27.67	34.81	22.38		0.57
46	27.60	34.80	22.40		0.57
76	27.45	34.81	22.45		0.59
90	26.84	34.90	22.72		0.74
105	26.86	34.99	22.78		0.70
118	25.82	34.94	23.06		0.93
130	23.08	34.92	23.87		1.14
130					1.09
144	20.65	34.87	24.51		1.41
144					1.33
160	16.60	34.76	25.44		1.57
175	12.44	34.64	26.24		1.96
175					2.04
208	10.86	34.70	26.59		2.11
242	10.45	34.71	26.67		2.19
282	10.41	34.76	26.71		2.33
282					2.28

STATION 12

M/V Hugh M. Smith: Cruise 16, 3°02'N., 149°59'W., July 31, 1952.
Messenger time: 0427 GCT. Weather: 02, cloud coverage 1.
Wind: 120°, 19 kt. Sea: 5-8 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	27.47	34.84	22.47		0.54
45	27.43	34.85	22.49		0.57
45					0.53
72	27.31	34.86	22.54		0.56
97	26.72	35.05	22.87		0.69
110	26.72	35.06	22.87		0.83
121	26.52	35.08	22.95		0.76
133	23.03	34.87	23.85		1.08
146	17.78	34.79	25.18		1.48
158	13.98	34.64	25.93		1.71
171	13.10	34.61	26.09		1.78
197	11.46	34.77	26.53		2.03
234	11.18	34.80	26.60		1/
2/					

1/ No sample.

2/ Bottle pretripped.

STATION 13

M/V Hugh M. Smith: Cruise 16, 2°30'N, 150°02'W., July 31, 1952. Messenger time: 1015 GCT. Weather: 02, cloud coverage not recorded. Wind: 100°, 18 kt. Sea: 3-5 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.40	34.89	22.53		0.58
43	27.40	34.93	22.56		0.57
71	26.86	35.01	22.79		0.66
71					0.62
96	26.52	35.13	22.99		0.70
108	26.25	35.01	22.98		0.74
121	24.40	34.85	23.43		0.98
133	21.02	34.86	24.40		1.26
133					1.21
147	17.08	34.74	25.31		1.47
160	16.09	34.74	25.55		1.54
174	12.06	1/			1/
203	11.57	34.86	26.58		2.31
203					2.40
238	11.14	34.81	26.62		2.10
277	11.04	34.80	26.63		2.30

1/ No samples.

STATION 14

M/V Hugh M. Smith: Cruise 16, 1°57'N, 150°07'W., July 31, 1952. Messenger time: 1602 GCT. Weather: 80, cloud coverage 9. Wind: 110°, 17 kt. Sea: 3-5 ft. Wire angle: 45°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.26	34.93	22.60		0.51
41	27.26	34.92	22.60		0.51
66	26.84	35.01	22.80		0.57
89	26.42	35.03	22.94		0.68
99	25.42	34.94	23.19		0.82
110	24.66	34.99	23.46		0.84
122	22.54	34.90	24.01		0.93
135	17.70	34.73	25.16		1.30
147	15.72	34.68	25.58		1.43
160	13.76	34.63	25.97		1.59
160					1.65
188	11.87	34.83	26.50		2.28
226	11.28	34.77	26.56		2.09
266	11.08	34.77	26.60		2.14

STATION 15

M/V Hugh M. Smith: Cruise 16, 1°24'N., 149°57'W., July 31, 1952.
Messenger time: 2203 GCT. Weather: 03, cloud coverage 3.
Wind: 130°, 21 kt. Sea: 3-5 ft. Wire angle: 52°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.29	34.94	22.60		0.57
30	27.14	34.94	22.65		0.59
43	26.68	35.06	22.89		0.59
55	26.59	35.04	22.90		0.65
65	26.50	35.05	22.94		0.68
75	26.06	35.06	23.08		0.78
87	25.88	35.05	23.13		0.71
97	24.68	35.07	23.51		0.85
109	23.30	35.00	23.87		0.87
121	21.32	34.90	24.35		1.03
147	14.92	34.69	25.77		1.47
177	11.96	34.69	26.38		1.81
211	11.52	34.80	26.54		2.19
211	11.46	34.80	26.55		

STATION 16

M/V Hugh M. Smith: Cruise 16, 0°57'N., 150°01'W., August 1, 1952.
Messenger time: 0317 GCT. Weather: 02, cloud coverage 1.
Wind: 100°, 16 kt. Sea: 3-5 ft. Wire angle: 58°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
03	27.03	35.03	22.75		0.59
27	26.91	35.02	22.78		0.63
51	26.50	35.05	22.94		0.82
71	26.08	35.12	23.12		0.78
82	25.76	35.12	23.22		0.75
90	25.32	35.14	23.37		0.80
100	23.94	35.08	23.74		0.83
110	20.46	34.91	24.59		1.10
110					1.05
120	18.94	34.88	24.96		1.13
132	17.80	34.87	25.24		1.16
132					1.25
157	14.22	34.72	25.94		1.52
184	12.20	34.71	26.34		1.80
248	11.32	34.80	26.58		2.12

STATION 17

M/V Hugh M. Smith: Cruise 16, 0°28'N., 150°01'W., August 1, 1952. Messenger time: 0857 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: 57°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.48	35.08	22.96		0.70
04					0.64
28	26.43	35.08	22.98		0.67
52	26.03	35.14	23.15		0.67
73	25.38	35.21	23.40		0.76
82	24.97	35.20	23.52		0.78
89	24.24	35.19	23.73		0.86
99	22.41	35.10	24.20		0.94
108	20.94	35.12	24.62		1.03
121	17.34	35.03	25.47		1.26
134	17.24	35.14	25.58		1.32
162	14.38	34.91	26.05		1.55
195	12.77	34.90	26.38		1.74
271	11.64	34.82	26.53		1.99

STATION 18

M/V Hugh M. Smith: Cruise 16, 0°06'S., 149°55'W., August 1, 1952. Messenger time: 1432 GCT. Weather: 02, cloud coverage not recorded. Wind: 080°, 16 kt. Sea: 3-5 ft. Wire angle: 58°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.22	35.16	23.11		0.66
28	26.18	35.16	23.12		0.66
51	25.94	35.22	23.24		0.67
71	25.48	35.31	23.45		0.76
79	24.96	35.30	23.60		0.80
89	24.56	35.41	23.80		0.88
96	24.58	35.53	23.89		0.90
106	23.32	35.51	24.25		1.04
119	22.18	35.61	24.65		1.07
130	19.60	35.19	25.03		1.15
158	16.52	35.12	25.74		1.39
192	13.44	34.89	26.24		1.65
276	11.66	34.85	26.55		2.11

STATION 19

M/V Hugh M. Smith: Cruise 16, 0°39'S., 149°49'W., August 1, 1952.
Messenger time: 2012 GCT. Weather: 02, cloud coverage 5.
Wind: 130°, 21 kt. Sea: 8-12 ft. Wire angle: 55°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
03	26.22	35.22	23.15		0.53[1]
30	26.20	35.22	23.16		0.56
58	26.10	35.28	23.24		0.55
83	25.96	35.44	23.40		0.60
108	24.60	35.96	24.21		0.78
108					0.84
120	22.37	35.79	24.73		0.93
131	18.88	35.38	25.36		1.02
145	17.48	35.35	25.68		1.21
161	15.70	35.18	25.97		1.26
178	14.24	34.97	26.13		1.35
234[2]	12.10	34.88	26.50		1.80
320	11.08	34.83	26.65		2.11

[1] The phosphate analysis on this station appears to have been faulty; all values are somewhat low.

[2] Bottle pretripped.

STATION 20

M/V Hugh M. Smith: Cruise 16, 0°59'S., 149°50'W., August 2, 1952.
Messenger time: 0033 GCT. Weather: 02, cloud coverage 1.
Wind: 090°, 17 kt. Sea: 5-8 ft. Wire angle: 52°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.44	35.28	23.13		0.72
32	26.32	35.27	23.16		0.73
61	26.28	35.14	23.07		0.70
90	26.25	35.45	23.31		0.80
103	26.28	35.55	23.38		0.83
116	23.36	35.87	24.51		1.09
127	21.04	35.83	25.13		1.14
140	19.07	35.61	25.49		1.33
156	15.92	35.33	26.04		1.58
169	14.30	35.06	26.19		1.56
203	13.78	35.07	26.30		1.69
239	11.82	34.90	26.56		2.22
321	11.31	34.86	26.63		2.26

STATION 21

M/V Hugh M. Smith: Cruise 16, 1°28'S., 149°45'W., August 2, 1952. Messenger time: 0527 GCT. Weather: 02, cloud coverage not recorded. Wind: 090°, 18 kt. Sea: 5-8 ft. Wire angle: 29°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.52	35.35	23.16		0.69
44	26.49	35.38	23.19		0.70
87	26.57	35.50	23.25		0.68
131	21.04	35.75	25.07		1.15
152	16.14	35.35	26.00		1.58
175	14.72	35.17	26.18		1.72
197	12.88	34.98	26.42		2.18
220	12.35	34.92	26.48		2.32
242	12.16	34.89	26.49		2.38
264	11.96	34.90	26.54		2.47
264					2.38
310	11.46	34.84	26.58		2.60
355	10.78	34.85	26.72		2.68
448	08.28	34.72	27.03		2.77
448					2.73

STATION 22

M/V Hugh M. Smith: Cruise 16, 1°58'S., 149°48'W., August 2, 1952. Messenger time: 1058 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 16 kt. Sea: 5-8 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	26.90	35.63	23.25		0.73
49	26.91	35.64	23.25		0.72
97	26.88	35.61	23.24		0.70
122	23.32	35.68	24.38		1.10
146	17.14	35.37	25.78		1.56
170	14.77	35.15	26.16		1.93
195	12.76	34.95	26.42		2.31
219	12.40	34.94	26.48		2.27
244	12.14	34.91	26.51		2.25
268	11.83	34.94	26.59		2.24
293	11.66	34.87	26.57		2.35
343	10.68	34.80	26.70		2.69
394	09.60	34.71	26.81		2.86

STATION 23

M/V Hugh M. Smith: Cruise 16, 2°29'S., 149°53'W., August 2, 1952.
Messenger time: 1633 GCT. Weather: 03, cloud coverage 5.
Wind: 090°, 18 kt. Sea: 3-5 ft. Wire angle: 10°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.10	35.56	23.13		0.55[1]
49	27.10	35.58	23.15		0.55
77	27.00	35.59	23.18		0.53
97	26.67	35.60	23.30		0.62
117	23.44	35.70	24.36		0.92
135	19.92	35.61	25.27		1.12
155	14.36	35.12	26.22		1.88
172	12.72	34.94	26.42		2.24
192	12.56	34.95	26.46		2.18
216	12.28	34.93	26.50		2.08
264	11.75	34.88	26.56		2.27
312	11.42	34.86	26.61		2.14
386	10.36	34.80	26.75		2.48

[1] The phosphate analysis on this station appears to have been faulty; all values are somewhat low.

STATION 24

M/V Hugh M. Smith: Cruise 16, 2°59'S., 149°59'W., August 2, 1952.
Messenger time: 2203 GCT. Weather: 02, cloud coverage 2.
Wind: 120°, 15 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.37	35.52	23.01		0.74
05					0.69
45	27.24	35.54	23.07		0.73
72	27.22	35.53	23.07		0.66
72					0.75
89	27.12	35.52	23.09		0.73
103	25.76	35.66	23.62		0.93
116	22.10	35.61	24.67		1.20
116					1.13
129	20.82	35.61	25.02		1.29
143	17.82	35.44	25.67		1.54
161	14.18	35.09	26.23		2.15
161					2.01
179	12.86	34.96	26.41		2.37
225	11.93	34.88	26.53		2.35
271	11.52	34.86	26.59		2.19
364	10.32	34.78	26.74		2.33

STATION 25

M/V Hugh M. Smith: Cruise 16, 3°29'S., 149°57'W., August 3, 1952.
Messenger time: 0319 GCT. Weather: 02, cloud coverage 4.
Wind: 120°, 20 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.41	35.40	22.91		0.67
44	27.28	35.43	22.97		0.66
68	27.26	35.44	22.99		0.62
84	27.26	35.43	22.98		0.65
96	27.28	35.41	22.96		0.65
108	26.42	35.68	23.43		0.80
120	23.65	35.82	24.38		0.95
131	19.59	35.52	25.28		1.34
143	15.62	35.21	26.01		1.76
161	13.15	34.99	26.37		2.27
199	12.32	34.92	26.43		2.34
238	11.72	34.87	26.56		2.31
325	10.61	34.81	26.71		2.28

STATION 26

M/V Hugh M. Smith: Cruise 16, 3°59'S., 150°05'W., August 3, 1952.
Messenger time: 0835 GCT. Weather: 02, cloud coverage 9.
Wind: 110°, 15 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.24	35.47	23.02		0.67
43	27.24	35.45	23.00		0.65
67	27.18	35.48	23.04		0.61
83	27.20	35.45	23.01		0.64
95	27.21	35.45	23.01		0.63
106	27.18	35.46	23.03		0.65
117	26.59	35.64	23.35		0.78
129	24.09	35.85	24.28		0.93
140	19.52	35.56	25.33		1.29
157	16.32	35.26	25.89		1.72
192	12.56	34.91	26.43		2.26
231	11.77	34.87	26.55		2.21
311	10.43	34.78	26.72		2.14

STATION 27

M/V *Hugh M. Smith*: Cruise 16, 4°29'S., 150°12'W., August 3, 1952. Messenger time: 1357 GCT. Weather: 02, cloud coverage not recorded. Wind: 120°, 16 kt. Sea: 3-5 ft. Wire angle: 29°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.21	35.29	22.89		0.66
63	27.19	35.41	22.99		0.65
82	27.15	35.43	23.01		0.64
94	27.14	35.46	23.04		0.65
105	27.16	35.47	23.04		0.66
117	26.94	35.53	23.16		0.70
128	25.36	35.73	23.80		0.81
128					0.86
139	20.48	35.68	25.17		1.12
150	17.63	35.35	25.65		1.48
164	15.50	35.22	26.05		1.71
193	13.54	35.05	26.34		1.89
231	12.32	34.94	26.50		1.91
312	10.50	34.79	26.72		2.19

STATION 28

M/V *Hugh M. Smith*: Cruise 16, 5°02'S., 150°12'W., August 3, 1952. Messenger time: 1920 GCT. Weather: 25, cloud coverage 3. Wind: 120°, 17 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.29	35.43	22.97		0.58
04					0.74
63	27.28	35.41	22.96		0.58
83	27.27	35.43	22.97		0.52
83					0.47
96	27.26	35.46	23.00		0.60
108	27.26	35.49	23.03		0.56
120	27.18	35.44	23.01		0.63
132	25.96	35.62	23.53		0.73
144	23.40	35.73	24.39		0.96
156	19.94	35.58	25.24		1.13
173	16.62	35.37	25.91		1.52
206	12.84	34.98	26.43		1.92
249	11.36	34.86	26.62		2.05
335	10.09	34.78	26.79		2.24

STATION 29

M/V *Hugh M. Smith*: Cruise 16, 6°00'S., 150°10'W., August 4, 1952. Messenger time: 0326 GCT. Weather: 01, cloud coverage 1. Wind: 120°, 18 kt. Sea: 3-5 ft. Wire angle: 22°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.41	35.51	22.99		0.66
55	27.30	35.51	23.03		0.65
92	27.28	35.53	23.05		0.61
128	27.10	35.60	23.16		0.70
146	23.67	35.81	24.37		0.99
164	21.36	35.81	25.03		1.02
182	18.26	35.48	25.59		1.23
200	15.78	35.19	25.96		1.48
218	13.26	34.97	26.33		1.94
236	12.22	34.90	26.49		2.06
272	11.19	34.87	26.66		2.14
308	09.83	34.76	26.81		2.25
364	09.22	34.72	26.88		2.24

STATION 30

M/V *Hugh M. Smith*: Cruise 16, 6°58'S., 150°05'W., August 4, 1952. Messenger time: 1133 GCT. Weather: 02, clear. Wind: 100°, 17 kt. Sea: 3-5 ft. Wire angle: 32°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.67	35.31	22.75		0.60
63	27.50	35.44	22.91		0.60
94	27.39	35.51	23.00		0.58
115	27.31	35.51	23.03		0.64
128	27.19	35.61	23.14		0.66
141	26.68	35.92	23.53		0.79
153	25.08	36.05	24.13		0.86
153					0.96
171	21.88	35.89	24.94		0.98
192	18.52	35.51	25.55		1.15
214	15.10	35.13	26.07		1.54
258	12.20	34.85	26.45		2.07
303	10.49	34.76	26.70		2.23
350	09.32	34.69	26.84		2.28

MID-PACIFIC OCEANOGRAPHY
Parts II and III
Transequatorial Waters, 1950-51

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 131

UNITED STATES DEPARTMENT OF THE INTERI
FISH AND WILDLIFE SERVI

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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Fish and Wildlife Service, John L. Farley, Director

MID-PACIFIC OCEANOGRAPHY II
By
Townsend Cromwell

and

MID-PACIFIC OCEANOGRAPHY III
By
Thomas S. Austin

Special Scientific Report: Fisheries No. 131

WASHINGTON: JUNE 1954

MID-PACIFIC OCEANOGRAPHY II

TRANSEQUATORIAL WATERS

JUNE - AUGUST 1950

JANUARY - MARCH 1951

By

TOWNSEND CROMWELL[1]

PACIFIC OCEANIC FISHERY INVESTIGATIONS

HONOLULU, T. H.

1/ Presently employed at Scripps Institution of Oceanography, La Jolla, California

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MID-PACIFIC OCEANOGRAPHY - II

Introduction

This is the second in a series of reports planned to present oceanographic data obtained by the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service. The first (Cromwell 1951) presented oceanographic data in tabular and graphical form with discussions of some of the results of cruise 2 of the Hugh M. Smith, the first equatorial cruise of the POFI program concerned primarily with the collection of physical and chemical data. This present report is concerned with Smith cruises 5 and 8, the second and third equatorial cruises with similar objectives.

The primary purpose of this report is to present the tabulated data and cross-section drawings.[2/] There is only a brief description of results and no attempt is made to relate the present work in a comprehensive fashion to that done by others in the equatorial Pacific.

The primary objective of these oceanographic studies in the equatorial Pacific is to provide information that may be related to biological productivity and particularly to the occurrence of the tunas. POFI's oceanographic program, up to the present time, has centered on describing the distributions of physical and chemical properties and on determining the regions where vertical motion of a type important to productivity occurs.

Vessel, Equipment, and Procedures

Vessel and vessel equipment: The Hugh M. Smith is a former U. S. Navy YP of 700 dead weight tons, converted to carry out oceanographic and fishing research. A previous report (Cromwell 1951) provides a photograph of the vessel and describes the oceanographic and other scientific equipment aboard.

Collection of data: The methods used at sea to collect physical and chemical data were essentially as described in the report mentioned above. Serial temperature observations were made using protected reversing thermometers. Water samples were obtained using Nansen-type bottles (see frontispiece). The concentrations of dissolved oxygen were determined by the Winkler titration

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[2/] All cross-sections and tabulated data are grouped at the end of the text.

method and of the dissolved inorganic phosphate by the Automatic Servo-operated Photometer (Snodgrass et al. 1953). Portions of each water sample were stored in citrate bottles and returned to the Honolulu laboratory for chlorinity analysis by the Knudsen method.

Processing of data: Sampling depths were determined using reversing thermometers. The readings of protected and unprotected thermometers were adjusted to in situ values by means of graphs. Thermometric depths were computed and plotted on a graph of wire length minus thermometric depth against wire length as developed by R. O. Reid and described by La Fond (1951). The actual depths at which all water samples were obtained were determined from this curve.

Analyses of data: The analyses of the data (their preparation from the tables listing observed values to final presentation in the form of cross sections) were carried out differently from those reported by Cromwell (1951) for cruise 2. Data from that report have been re-analyzed and the resulting set of cross sections appear, in part, in a report by Cromwell (1953) and the remainder in a paper by Montgomery (1954).

For this report, the treatment of data was similar to that employed by Montgomery for one series of Smith stations along the 158° W. meridian (Montgomery 1954). The procedure followed here will be described briefly for those who do not have access to his paper and to point out differences from his method.

A temperature-vs.-depth curve was drawn for each station, the curve passing through each observed point (fig. 1). The BT trace was used to define detail in drawing the upper 200 meters of the curve. A temperature-salinity (T-S) curve then was drawn on the same graph using the same temperature scale. Thus, the depth or depths of occurrence of any particular salinity can be determined by referring to the temperature-depth curve. Successive T-S curves were placed on a light table and altered, where necessary, so that the station-to-station changes were as regular as the data would allow. Since curves along which sigma-t is constant appear printed on the graph, the depth of any particular value of sigma-t can be read by referring to the temperature-depth curve.

In constructing the cross sections, the depths of selected values for salinity and sigma-t were determined as above and plotted against distance. The isopleths were penciled lightly on the cross section. In addition, the values of actual observations were written onto a second cross section using an equivalent pair of scales. The two were superimposed on a light table and the isopleths modified consistent with the observed values. Up to this point in the treatment of the data, the procedures follow closely those described by Montgomery (1954).

Montgomery used an analogous procedure to construct cross sections for inorganic phosphate and oxygen. The method used here for these two fields was less rigorous but also less time consuming. The observed values of inorganic phosphate were written onto a cross section using depth and distance scales equivalent to those used in drawing the sigma-t section. This sheet was then placed over the completed sigma-t section on the light table. The isopleths were drawn as nearly as possible along the sigma-t surfaces, but not in violation of any of the observed values. This was done in accordance with the principle used in isentropic analysis, namely, that water flows along surfaces of constant potential density (under certain conditions rather generally encountered in the ocean), these surfaces being very nearly coincident with surfaces of constant sigma-t. The same procedure was used in constructing the oxygen cross sections. Neither inorganic phosphate nor oxygen is a conservative property, but proceeding as though they are probably leads to the most accurate cross sections possible in the absence of quantitative information about the biological processes.

Some Results of Hugh M. Smith Cruises 5 and 8

The station pattern for the June - August cruise of 1950, cruise 5, appears as figure 2 while that for the January - March cruise of 1951, cruise 8, is shown in figure 3. Each of these two cruises comprised primarily two lines of stations, one each along 158° W. and 172° W. Cruise 8 included additional stations along a zigzag course between 155° W. and 169° W. longitude.

The cross sections appearing as figures 4 - 32 are based on data collected along the four meridional station lines and stations 62-76 of cruise 8 along a NNE-SSW course (fig. 3). Figures 4-10 result from data collected along the station line 1-27 of Smith cruise 5 (fig. 1), primarily along 172° W. longitude. These figures are in the sequence dynamic topography, geostrophic currents, BT, sigma-t, salinity, phosphate, and oxygen. This sequence is repeated for each long line of stations on Smith cruises 5 and 8, except that the sigma-t, salinity, phosphate, and oxygen sections based on stations 28-51 of Smith cruise 5 appear elsewhere (Cromwell 1953) and are not reproduced here. Stations 27-61, on the zigzag portion of Smith cruise 8, are not represented by cross sections.

Dynamic heights: Figures 4, 11, 14, 20, and 26 show the smoothed profiles of isobaric surfaces with respect to the 1,000-decibar surface. The dots represent the actual results of dynamic computations and are plotted to show what liberties with the data have been taken in the smoothing process.

Geostrophic currents: The relative currents, figures 5, 12, 15, 21, and 27, were computed from the smoothed profiles shown in figures 4, 11, 14, 20, and 26 respectively. The isovels indicate the component of geostrophic flow perpendicular to the plane of the cross section. They are not drawn between the 3-1/2° parallels because flow close to the Equator is not even approximately geostrophic. East currents are hatched.

The cross sections exhibit a complicated arrangement of zonal components of currents. There is some uncertainty in the existence of the lesser flows, particularly in the narrow currents that are based on only two or three stations. It is apparent, however, that there are appreciable regions of easterly flow existing outside the bounds of the Equatorial Countercurrent.

Table I is included to aid in identifying the currents that appear in the figures and to summarize pertinent information about them. The positions to the nearest one-half degree of latitude of the surface boundaries of the Equatorial Countercurrent were read from the figures of dynamic height. The number listed under "Core of Countercurrent" is the latitude of the maximum speed through the plane of the traverse as read from the figures showing geostrophic current. Values within parentheses are uncertain.

Table I

Longitude	Figure numbers	Dates of traverse	Southern boundary of Countercurrent	Northern boundary of Countercurrent	Core of Countercurrent
158°W.	11 and 12	Aug. 1-2, 1950	5°N.	9°N.	7-1/2°N.
158°W.	14 and 15	Jan. 19-22, 1951	2°N.	9-1/2°N.	(5-1/2°N.)
172°W.	4 and 5	July 7-9, 1950	(3-1/2°N.)	8°N.	6°N.
172°W.	26 and 27	Mar. 6-8, 1951	4°N.	10°N.	5-1/2°N.
166°W.	20 and 21	Feb. 12, 1951	5°N.	--	5-1/2°N.

Referring to figures 11 and 12, for example, the east-flowing Equatorial Countercurrent appears between 5° N. and 9° N., with the North Equatorial Current immediately adjacent to the north. South of the southern boundary of the Countercurrent there is a major flow toward the west, the South Equatorial Current. Since the currents near the Equator cannot be computed through use of the concept of the geostrophic current, the South Equatorial Current, and in some cases the Countercurrent, is interrupted on the sections.

Bathythermograph sections: Temperature sections, using the bathythermograph data, are reproduced in figures 6, 13, 16, 22, and 28.

Two bathythermograph observations were made at each hydrographic station and additional lowerings were made between stations. During cruise 5, BT casts were made at approximately 10-mile intervals. During cruise 8, BT casts were made at approximately 20- to 30-mile intervals except for closer, 10-mile intervals between the Equator and 5° - 7° N.

The curve at the top of each bathythermograph section describes the surface temperature and was drawn using the bucket temperatures smoothed with reference to the continuous-recording thermograph. In figure 6 between 5° 20' N. and 10° 00' N., and in figure 28 between 17° 00' N. and 18° 50' N., the surface temperature is relatively high and varies irregularly. This behavior is associated with light winds. During the times that these irregularities occurred, the wind speed was predominantly Beaufort force 1 and calm.

In figure 13 the surface temperature changes abruptly near 4° 20' N. This occurs at the surface intersection of the Equatorial Front, a feature which is described in some detail elsewhere (Cromwell 1953).

Sigma-t: In figures 7, 17, 23, and 29, the configuration of the sigma-t surfaces indicates relatively dense water in the surface layer near the Equator. This is associated with the equatorial upwelling. Nowhere else in the figure does the density of the surface layer indicate any appreciable addition of water from below.

The lines of constant sigma-t near the Equator bend downward in the lower part of, and just below, the thermocline. In figure 6, for example, the isopleths of sigma-t = 26.6 through sigma-t = 27.0 exhibit pronounced local depth maxima at the Equator. This feature appears in each of the sigma-t sections of this report, in the sections drawn by Cromwell (1953), and in the one by Montgomery (1954). It appears to be a prevalent feature of the central equatorial Pacific.

Salinity: The salinity cross sections are shown in figures 8, 18, 24, and 30. Regions of salinity greater than 34.8 °/oo are hatched.

Inorganic phosphate: Two phosphate sections were drawn and appear as figures 9 and 31. In figure 9, there are large variations in the concentration of inorganic phosphate below the thermocline. "Pools" of high or low concentration appear almost at alternate stations in the deeper water and often are found at stations where the concentrations in the surface layer are correspondingly high or low. This suggests that these variations are not in the ocean, but arise fictitiously in the determinations.

Surface water with a relatively high inorganic phosphate concentration appears near the Equator on both cross sections. This prevalent feature of the central Pacific is associated with the equatorial upwelling.

Oxygen: Oxygen sections appear as figures 10, 19, 25, and 32.

Acknowledgements

I wish to express my appreciation to Mary Lynne Godfrey, Richard V. Mead, and to those persons who worked with them in processing the physical data and plotting the sections. Winifred Tseu carried out the chlorinity titrations and processed the chemical data. Tamotsu Nakata drafted the figures. Thomas S. Austin made helpful suggestions and assisted generously in the later stages of the work.

The scientific field party during cruise 5 was: Joseph E. King (field party chief), Townsend Cromwell, Kenji Ego, Herbert Mann, Vernon Brock (Territorial Division of Fish and Game) and William Gosline (University of Hawaii). During cruise 8 the field party was: Joseph E. King (field party chief), Herbert Mann, Richard Mead, Stanley Peterson, Isaac Ikehara and Walter Kawano.

There were many other persons who assisted in this work at sea and ashore and I gratefully acknowledge their contributions.

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1953 An automatic servo-operated filter photometer. (In press).

REMARKS ABOUT THE OCEANOGRAPHIC DATA

Auxiliary station data:

Weather: Recorded according to the ww (present weather) code as it appears in the seventh edition of the U. S. Weather Bureau Circular M, Instructions to Marine Meteorological Observers. Parts of this code are changed in the 8th edition of the Circular M now in use.

Wind velocity: Measured using an anemometer located 30 m. above the sea surface. The observed direction is that from which the wind was blowing, given in degrees measured clockwise from north.

Tabulated data:

The surface temperature was observed to the nearest tenth of a degree. The hundredths digit appears always as a zero and has no significance.

On some stations, the "surface" Nansen bottle was lowered beneath the surface to avoid striking the side of the rolling vessel. On these stations, the minimum recorded observed depth is that of this top bottle in the cast as no bucket sample was taken.

Paired protected thermometers were used at most depths. When the corrected values are 0.05°C. or more in disagreement, the depth of observation is listed twice so that both temperature values may appear.

Pairs of determinations of inorganic phosphate concentration were made for each sample. If the two values of extinction differ by more than .05 (i.e., by more than approximately .20 µg at/l) the depth of the sample is listed twice so that both values of inorganic phosphate concentration may appear.

Values enclosed within parentheses have been extrapolated to their designated depths.

Cruise 5:

The surface temperature was measured using a bucket thermometer. The thermometer used during cruise 5, stations 1 through 28, read .2°C. too low so that a + .2°C. correction must be added to the values listed to obtain the correct surface temperature. A + .1°C. correction must be added to the surface temperature values listed for Smith cruise 5, stations 29 through 51.

Cruise 8:

Stations 3 and 5 were not occupied because of high winds.

During Smith cruise 8 the Nansen bottle that sampled at the seventh depth for which data are tabulated in this report did not always close properly. Although tabulated, the samples at this depth for stations 17, 65, 66, 80, 82-87, 91, and 104-106 appear to have been contaminated during retrieval of the cast and were not used in drawing the cross sections of this report.

During cruise 8 a large number of observations of inorganic phosphate concentration were lost because the stannous chloride solution was improperly protected from exposure to the air and oxidation of the stannous ion occurred. Examination of the results, particularly of the reagent blank values, indicate that the data of stations 1 through 76 are completely untrustworthy and so the values are deleted from the tabulated data and a cross section appears only for stations 77-106.

A + .1°C. correction must be added to all the surface temperature values of Smith cruise 8.

Figures

Frontispiece: Attaching Nansen bottle aboard the *Hugh M. Smith*.

1. Example of station data representation.
2. Station positions, *Hugh M. Smith* cruise 5.
3. Station positions, *Hugh M. Smith* cruise 8.

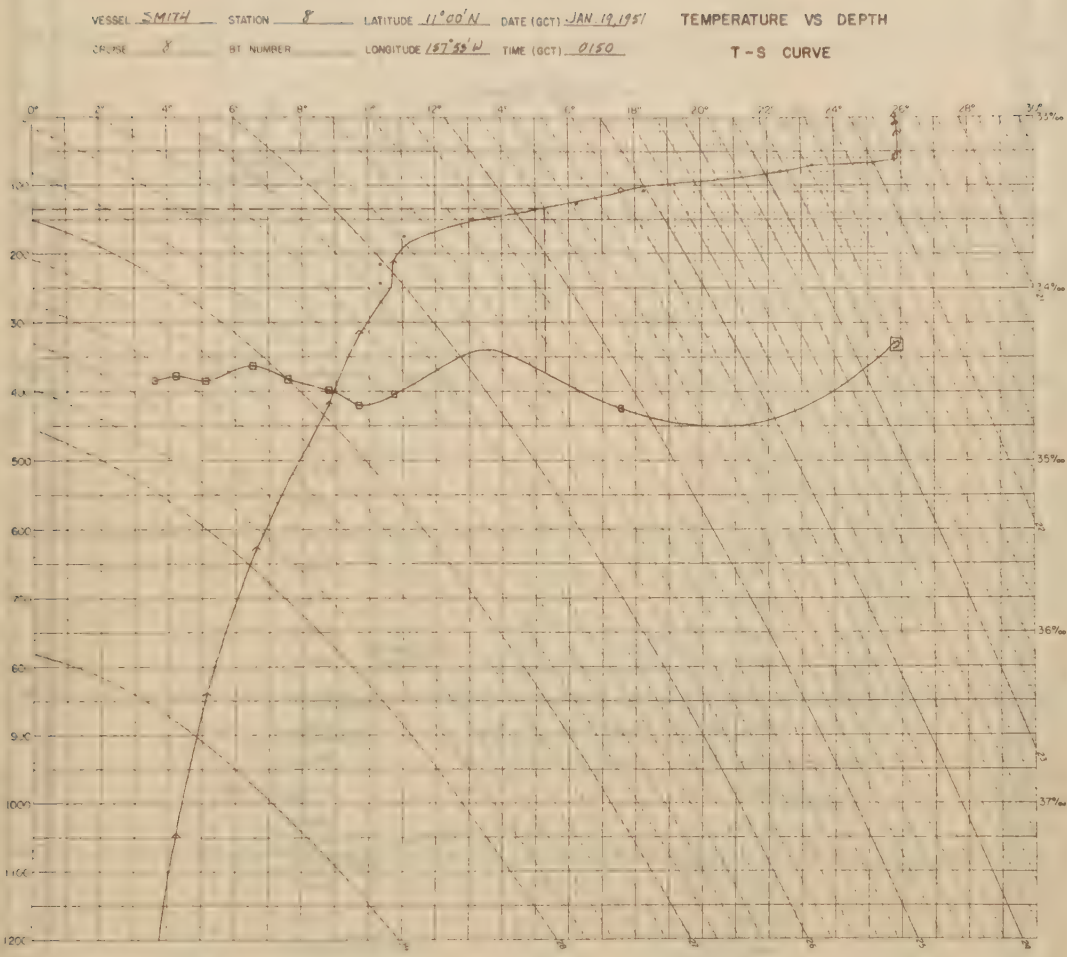
Cruise 5 - Hugh M. Smith

4. Dynamic topography, 172° W.
5. Geostrophic currents, 172° W.
6. Meridional section of temperature, 172° W.
7. Meridional section of density, 172° W.
8. Meridional section of salinity, 172° W.
9. Meridional section of phosphate, 172° W.
10. Meridional section of oxygen, 172° W.
11. Dynamic topography, 158° W.
12. Geostrophic currents, 158° W.
13. Meridional section of temperature, 158° W.

Cruise 8 - Hugh M. Smith

14. Dynamic topography, 158° W.
15. Geostrophic currents, 158° W.
16. Meridional section of temperature, 158° W.
17. Meridional section of density, 158° W.
18. Meridional section of salinity, 158° W.
19. Meridional section of oxygen, 158° W.
20. Dynamic topography, 165° - 170° W.
21. Geostrophic currents, 165° - 170° W.
22. Vertical section of temperature, 165° - 170° W.
23. Vertical section of density, 165° - 170° W.
24. Vertical section of salinity, 165° - 170° W.
25. Vertical section of oxygen, 165° - 170° W.
26. Dynamic topography, 172° W.
27. Geostrophic currents, 172° W.

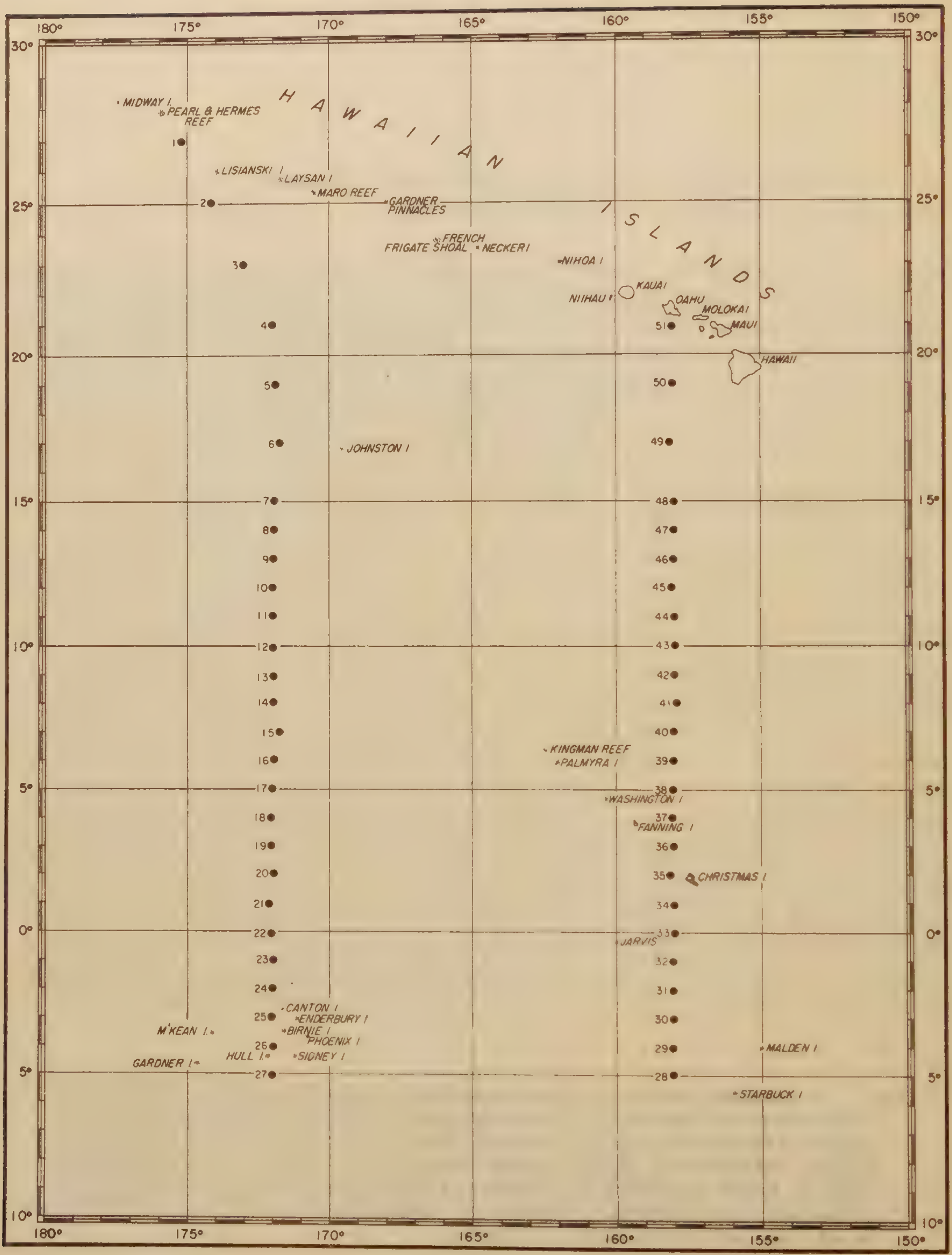
28. Meridional section of temperature, 172° W.
29. Meridional section of density, 172° W.
30. Meridional section of salinity, 172° W.
31. Meridional section of phosphate, 172° W.
32. Meridional section of oxygen, 172° W.



VESSEL SMITH STATION 8 LATITUDE 11°00'N DATE (GCT) JAN. 19, 1951

CRUISE 8 BT NUMBER LONGITUDE 157°59'W TIME (GCT) 0150

Fig. 1.-- Diagram used to represent temperature and salinity data. Points under an inverted V are the result of temperatures by reversing thermometers. Heavy points are those read from the BT trace. Points inside a square are the result of salinity observations, plotted against temperature. Dashed lines indicate the paths to follow in relating temperature, salinity, and sigma-t to depth. Thus, in the diagram at a depth of 133 meters the temperature is 15.28° C., the salinity, 34.49 ⁰/oo, and the sigma-t, 25.53 g/l.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PEARL & HERMES REEF
LISIANSKI I
LAYSAN I
MARO REEF
GARDNER PINNACLES
FRENCH FRIGATE SHOAL
NECKER I
NIHOA I
KAUAI
NIIHAU I
OAHU
MOLOKAI
MAUI
HAWAII
JOHNSTON I
KINGMAN REEF
PALMYRA I
WASHINGTON I
FANNING I
CHRISTMAS I
JARVIS
CANTON I
ENDERBURY I
BIRNIE I
PHOENIX I
M'KEAN I.
HULL I.
SIDNEY I
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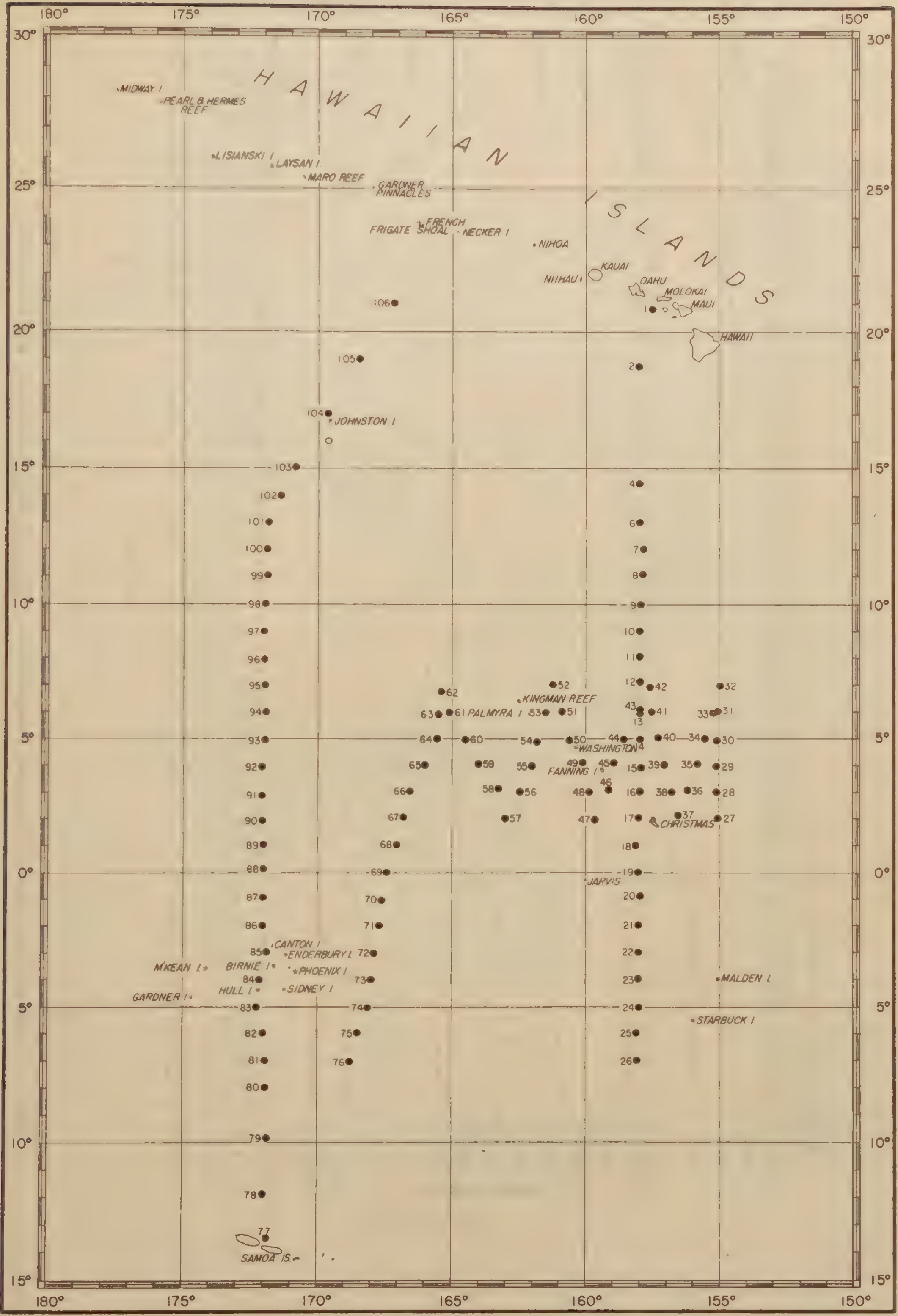
Fig. 2. -- Positions of hydrographic stations. Smith cruise 5, June - August 1950.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HAWAIIAN ISLANDS
MIDWAY I
PEARL & HERMES REEF
LISIANSKI I
LAYSAN I
MARO REEF
GARDNER PINNACLES
FRENCH FRIGATE SHOAL
NECKER I
NIHOA
NIIHAU
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
JOHNSTON I
KINGMAN REEF
PALMYRA I
WASHINGTON
FANNING I
CHRISTMAS
JARVIS
MALDEN I
STARBUCK I
CANTON I
ENDERBURY I
BIRNIE I
PHOENIX I
M'KEAN I
HULL I
SIDNEY I
GARDNER I
SAMOA IS.
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Fig. 3. -- Positions of hydrographic stations. Smith cruise 8, January - March 1951.

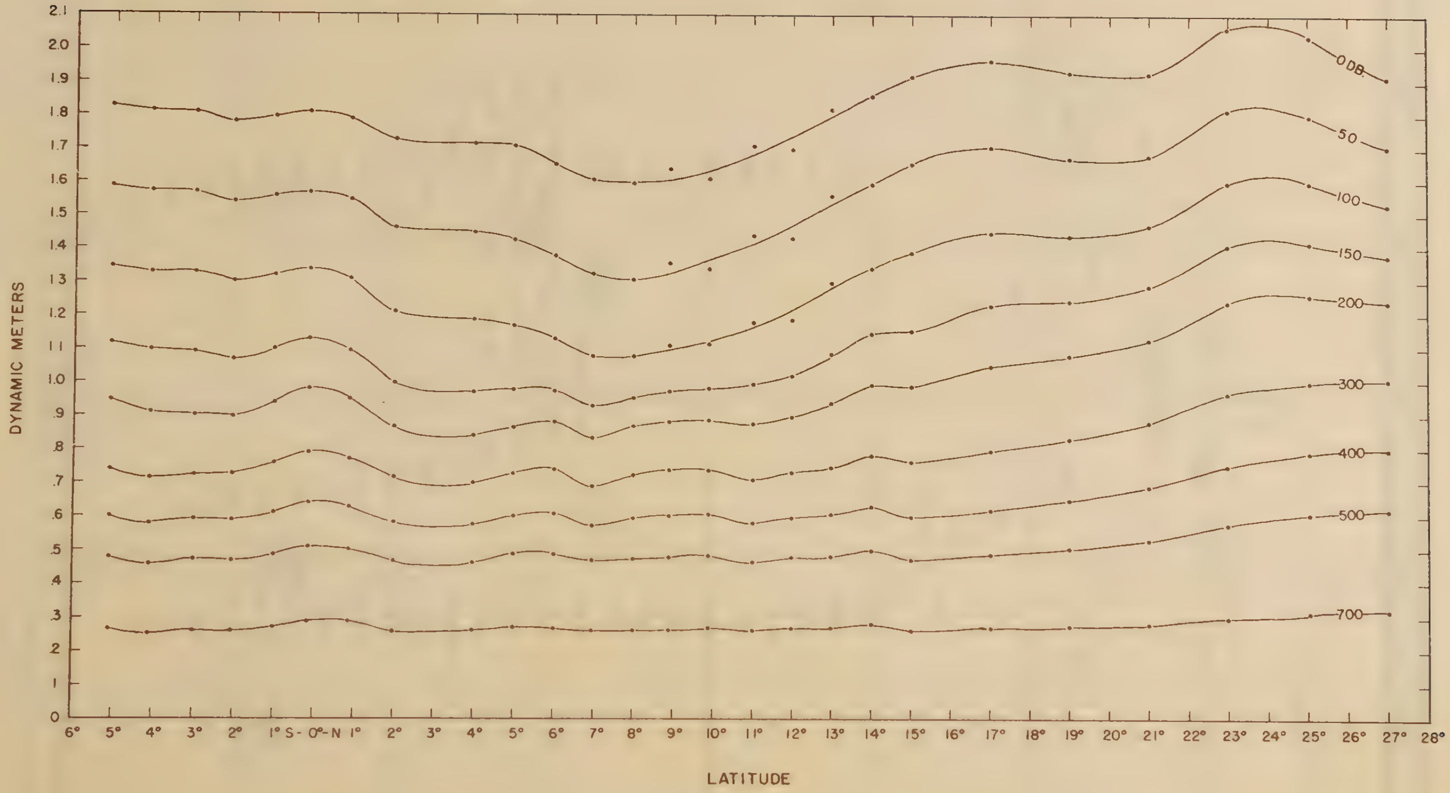

Fig. 4. -- Smoothed profiles of isobaric surfaces relative to the 1,000-decibar surface along 172° W., June 30 - July 12, 1950. Points are the result of dynamic computations. Hugh M. Smith cruise 5, stations 1-27.

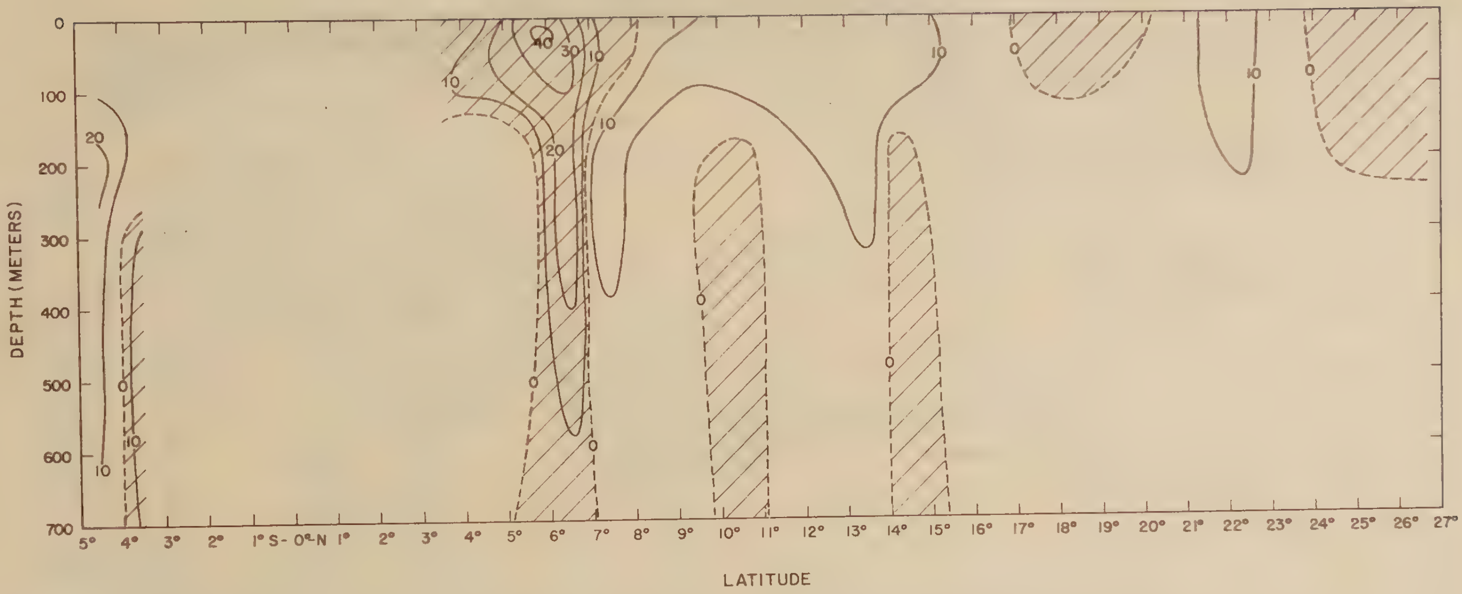

Fig. 5. -- Zonal components of the geostrophic currents across 172° W., June 30 - July 12, 1950. Computations based on smoothed profiles of isobaric surfaces (fig. 4). Current magnitude in cm/sec. East currents hatched. Hugh M. Smith cruise 5, stations 1-27.

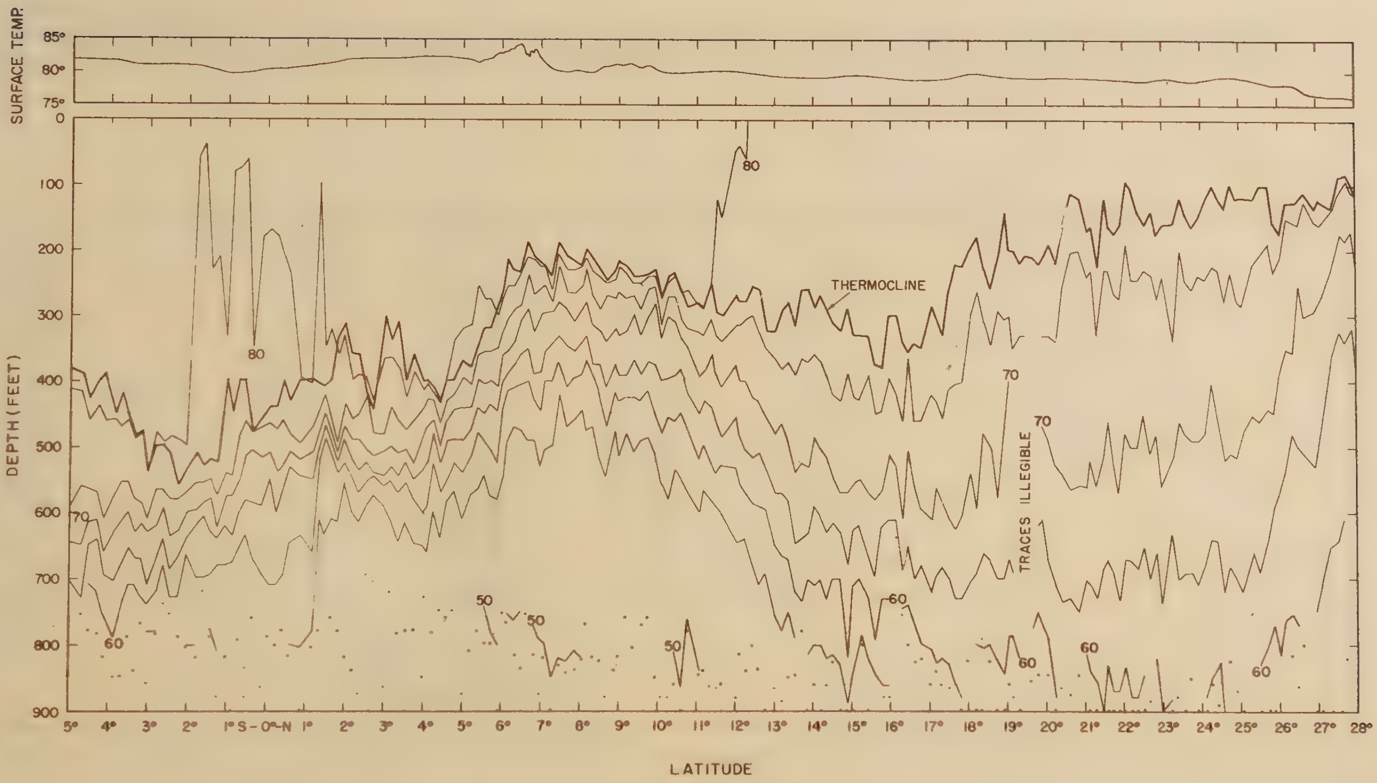

Fig. 6. -- *Above*, surface temperature and *below*, temperature section based on bathythermograph data along 172° W., June 30 - July 12, 1950. Isotherms drawn at intervals of 5° F. Dots indicate depths of observations. *Hugh M. Smith* cruise 5.

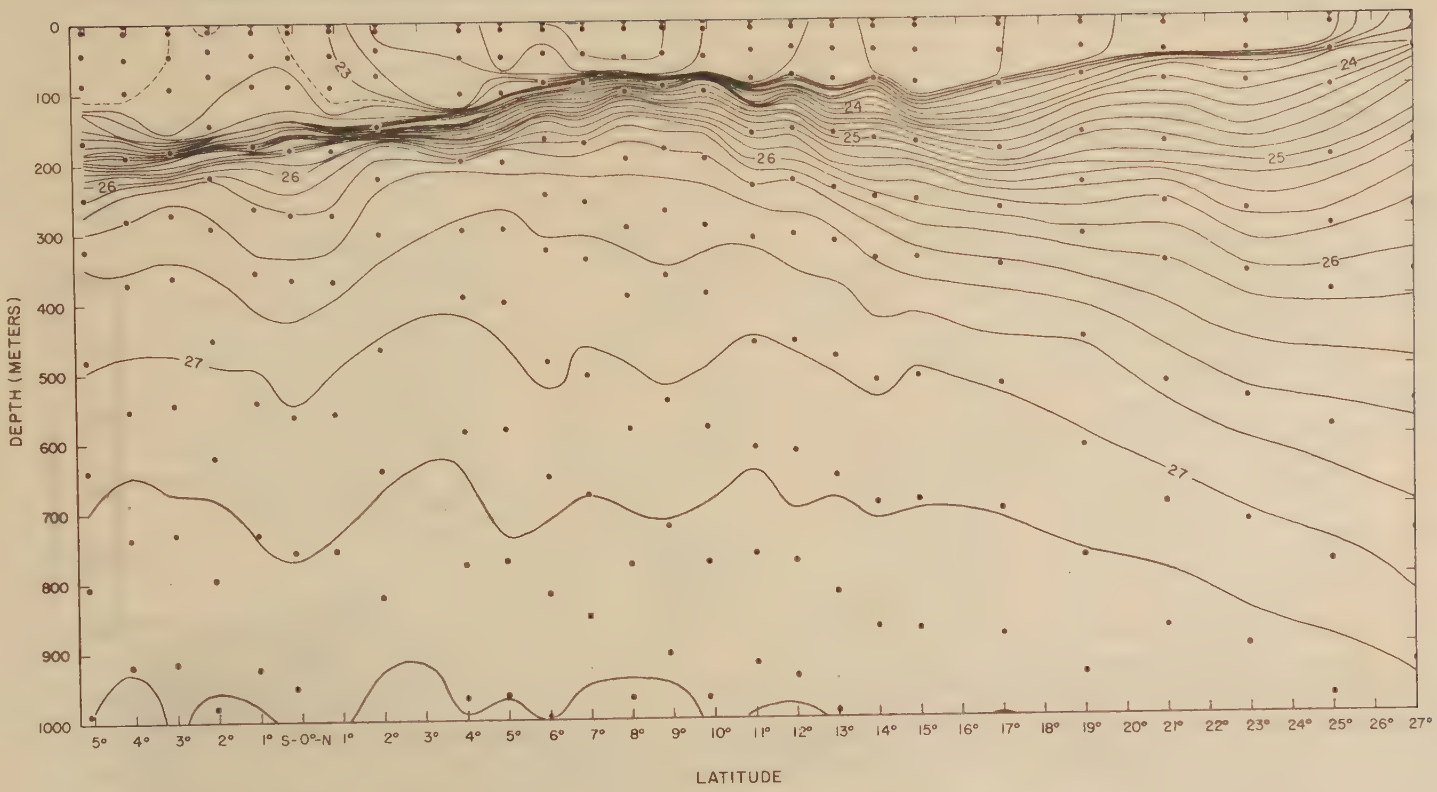

Fig. 7.-- Meridional section showing the distribution of density (σ_t) along 172° W., June 30 - July 12, 1950. Contour interval 0.2 g/l. Hugh M. Smith cruise 5, stations 1-27.

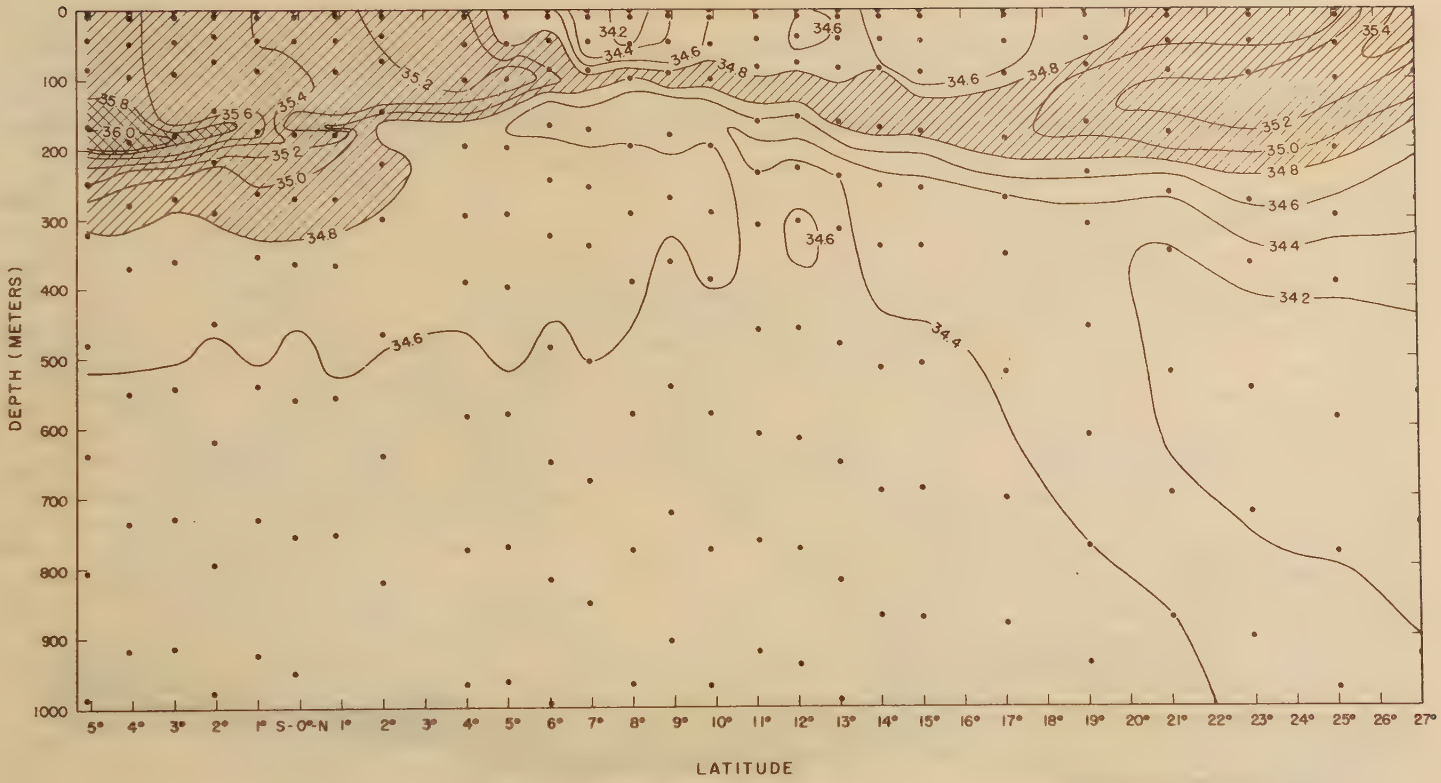

Fig. 8.-- Meridional salinity section along 172° W., June 30 - July 12, 1950. Contour interval 0.2 °/oo. Hugh M. Smith cruise 5, stations 1-27.

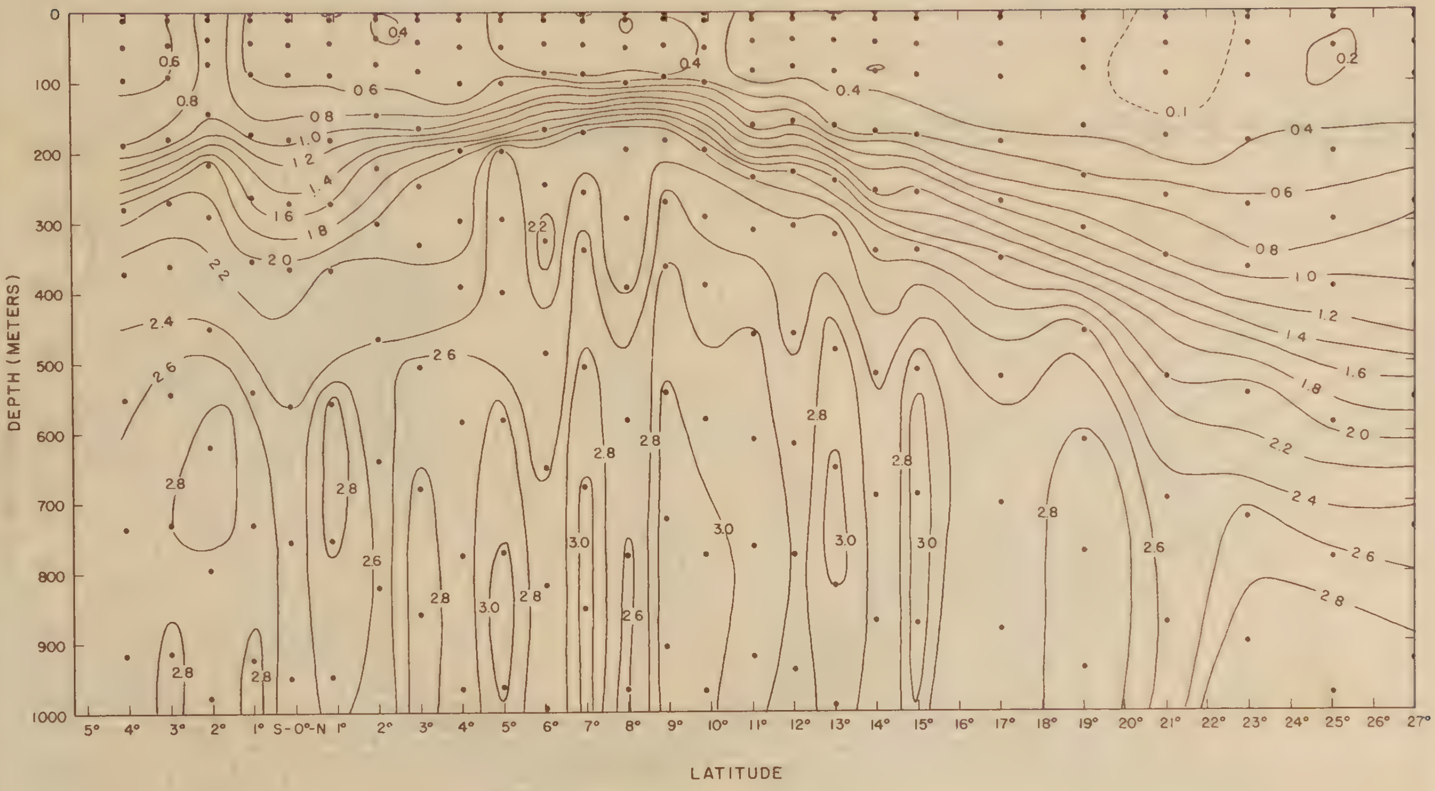

Fig. 9.-- Meridional section showing the concentration of inorganic phosphate along 172° W., June 30 - July 12, 1950. Contour interval 0.2 µg at/l. Hugh M. Smith cruise 5, stations 1-27.

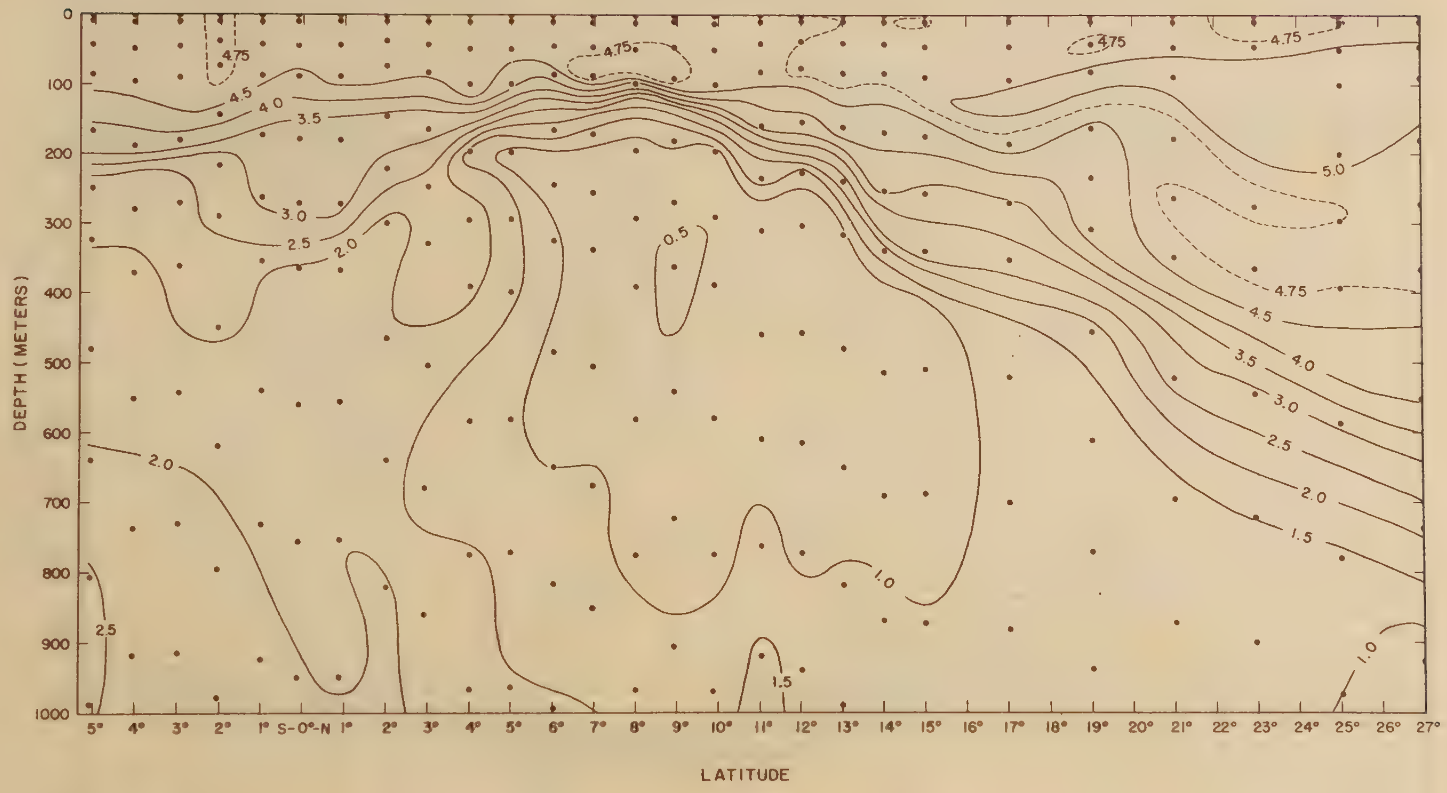

Fig. 10.-- Meridional section showing the concentration of dissolved oxygen along 172° W., June 30 - July 12, 1950. Contour interval 0.5 ml/l. Hugh M. Smith cruise 5, stations 1-27.

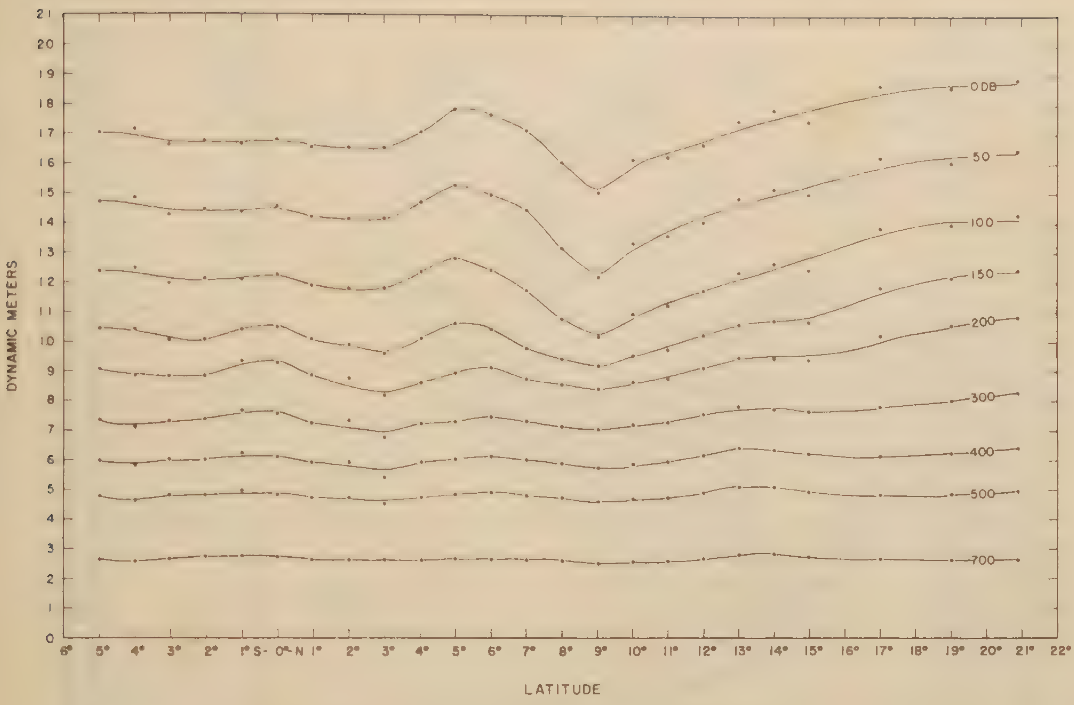

Fig. 11. -- Smoothed profiles of isobaric surfaces relative to the 1,000-decibar surface along 158° W., July 28 - August 6, 1950. Points are the result of dynamic computations. Hugh M. Smith cruise 5, stations 28-51.

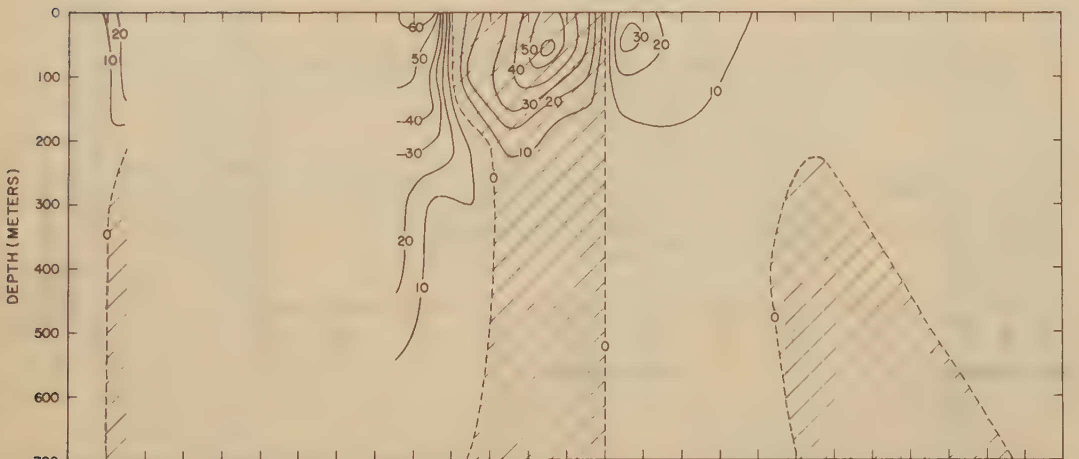

Fig. 12. -- Zonal components of the geostrophic currents across 158° W., July 28 - August 6, 1950. Computations based on smoothed profiles of isobaric surfaces (fig. 11). Current magnitude in cm/sec. East currents hatched. Hugh M. Smith cruise 5, stations 28-51.

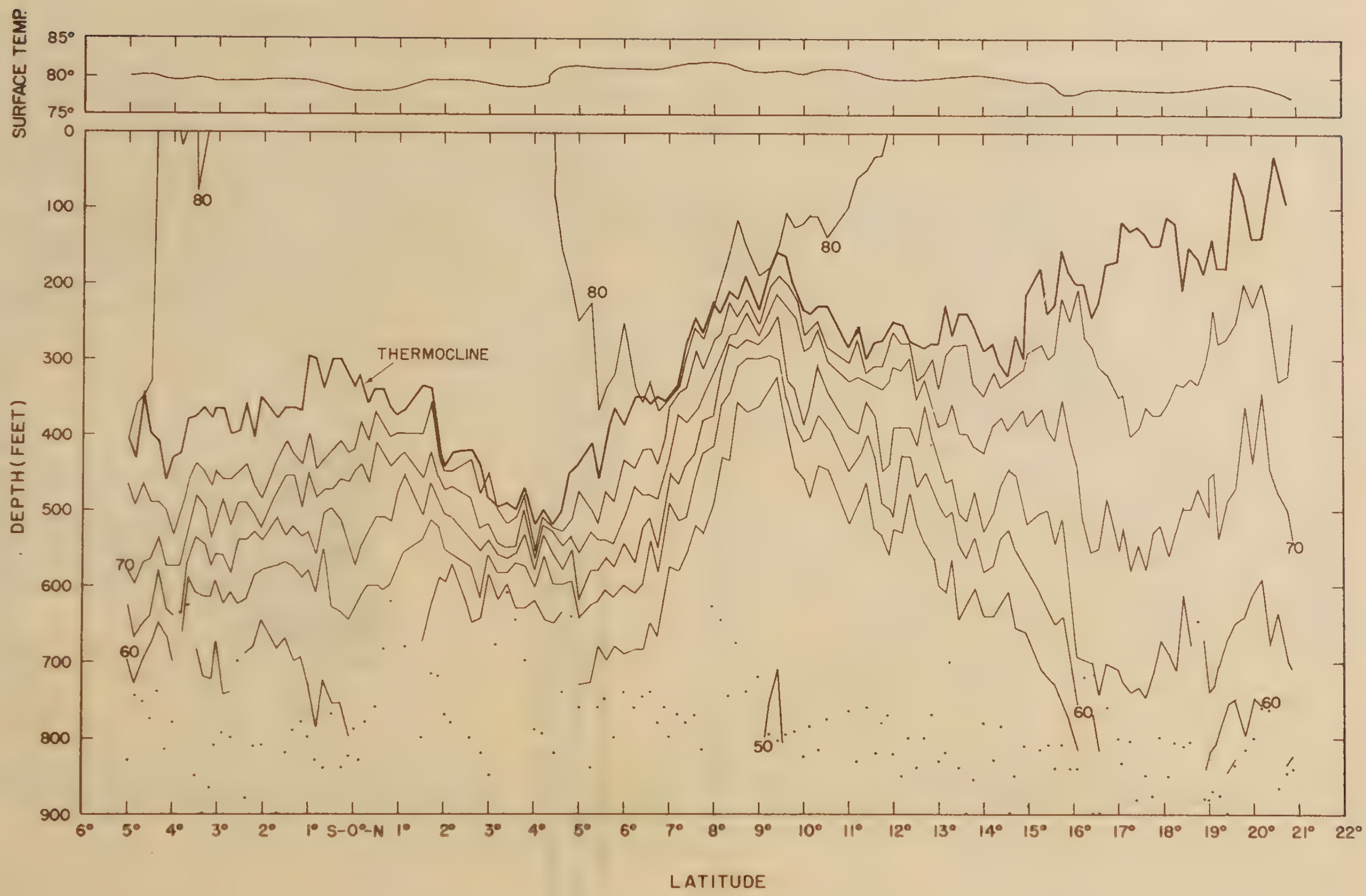

Fig. 13.-- Above, surface temperature and below, temperature section based on bathythermograph data along 158° W., July 28 - August 6, 1950. Isotherms drawn at intervals of 5° F. Dots indicate depths of observations. *Hugh M. Smith* cruise 5.

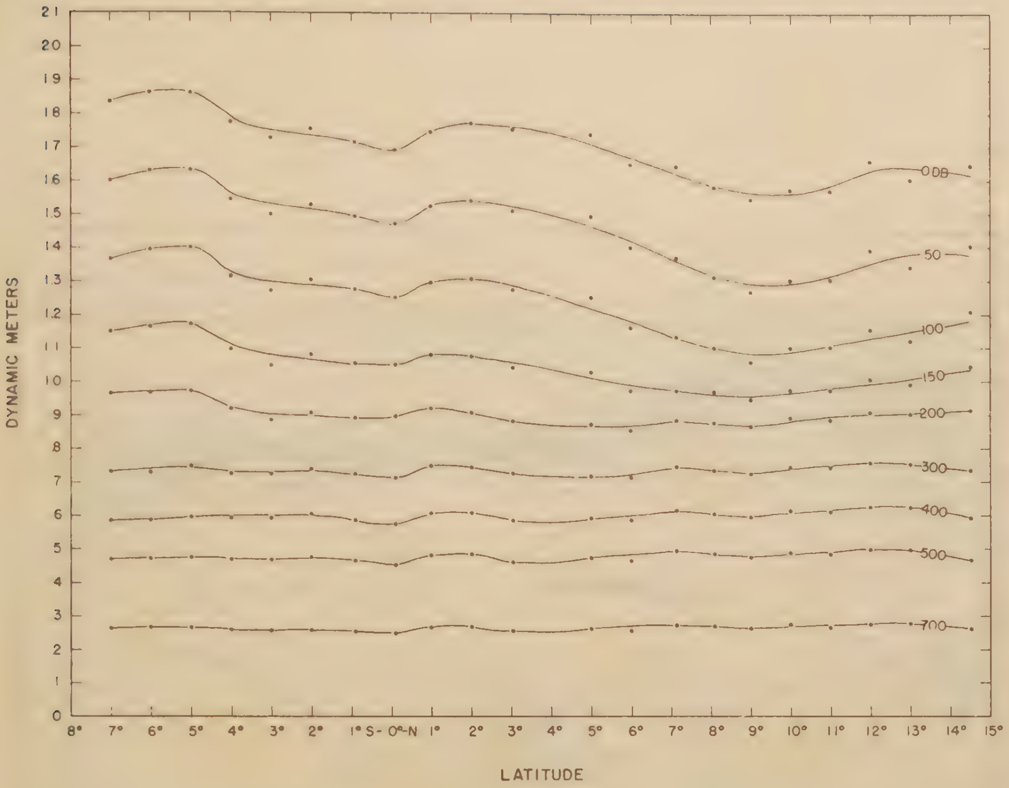

Fig. 14. -- Smoothed profiles of isobaric surfaces relative to the 1,000-decibar surface along 158° W., January 15 - 26, 1951. Points are the result of dynamic computations. Hugh M. Smith cruise 8, stations 1-26.

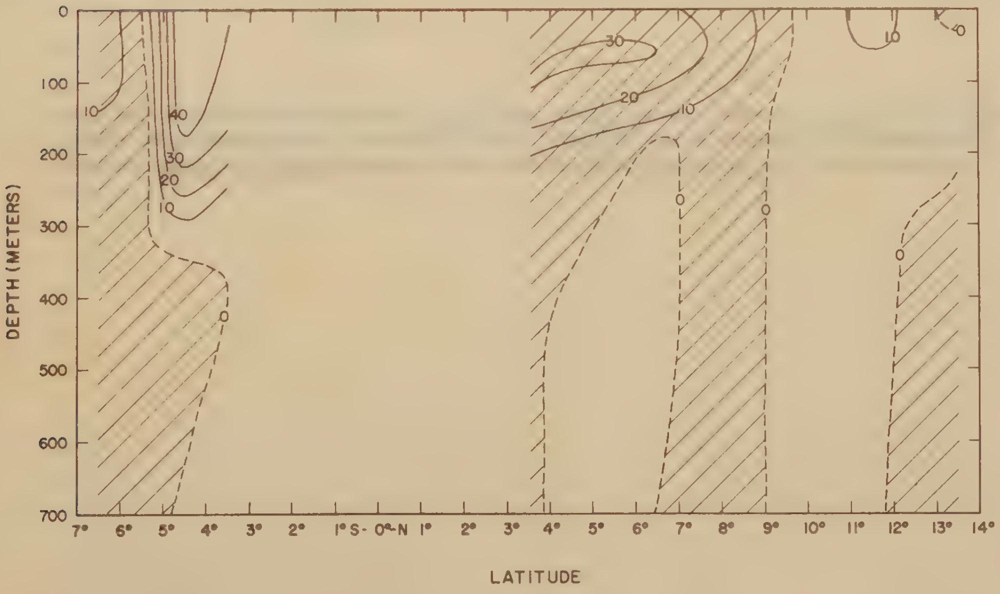

Fig. 15. -- Zonal components of the geostrophic currents across 158° W., January 15 - 26, 1951. Computations based on smoothed profiles of isobaric surfaces (fig. 14). Current magnitude in cm/sec. East currents hatched. Hugh M. Smith cruise 8, stations 1-26.

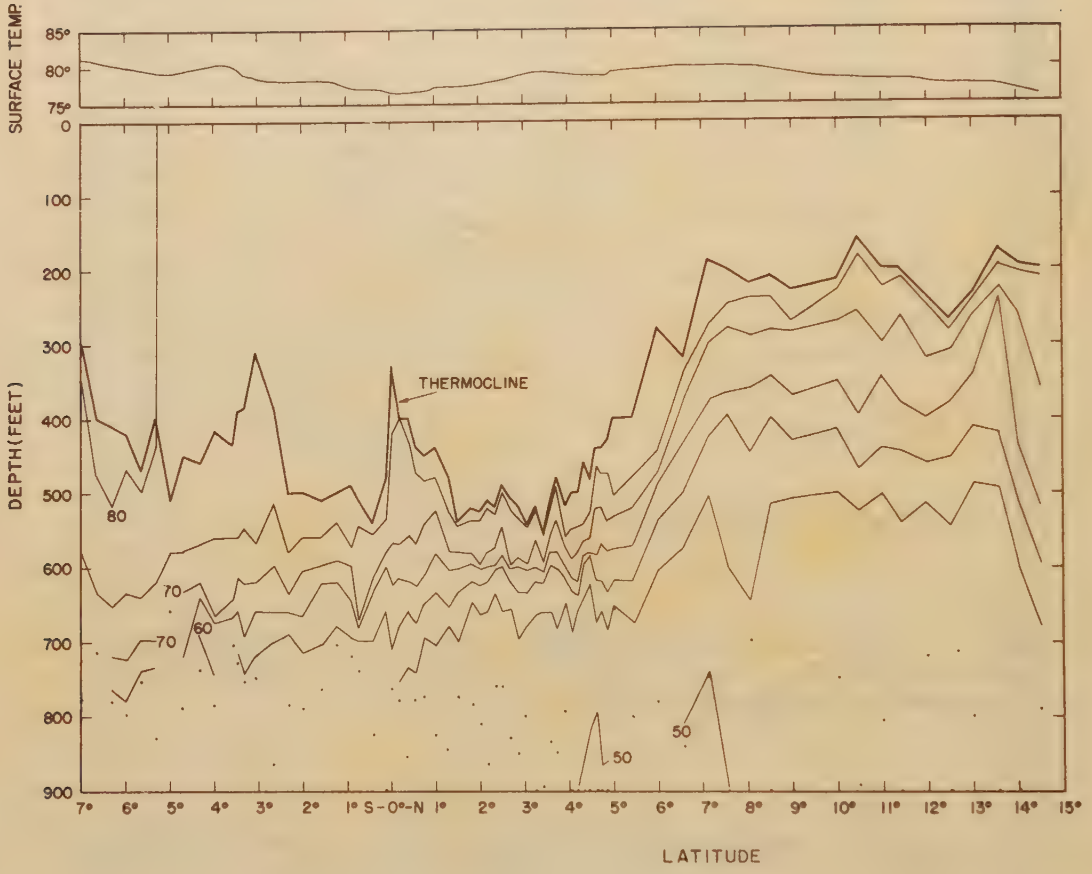

Fig. 16.-- Above, surface temperature and below, temperature section based on bathythermograph data along 158° W., January 15 - 26, 1951. Isotherms drawn at intervals of 5° F. Dots indicate depths of observations. *Hugh M. Smith* cruise 8.

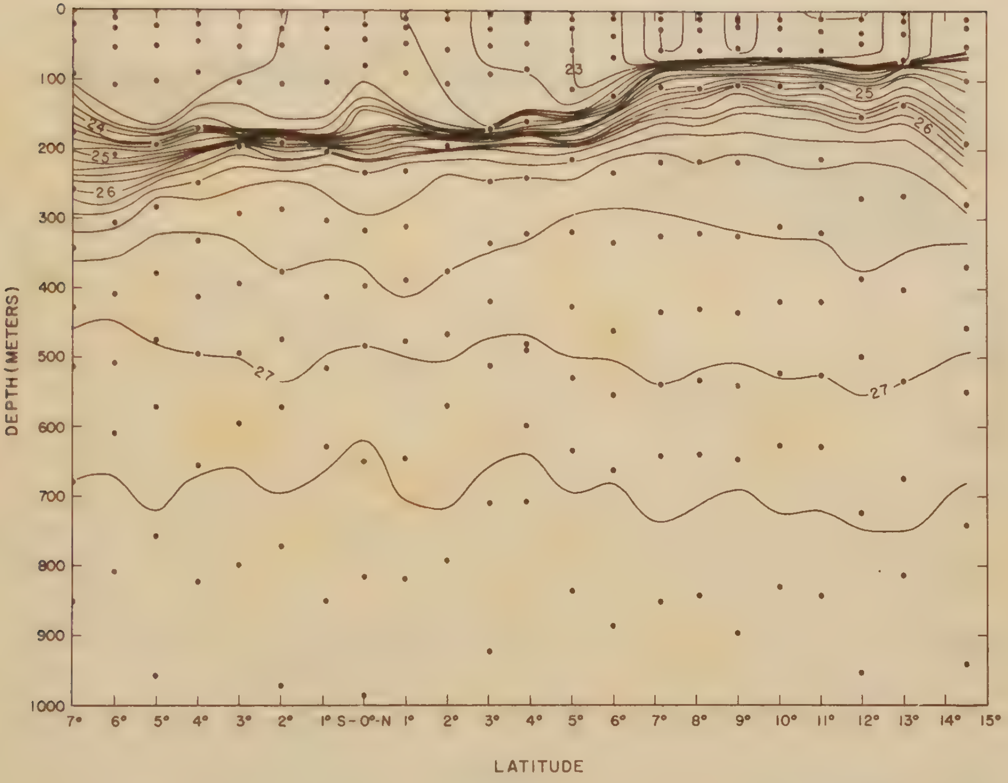

Fig. 17. -- Meridional section showing the distribution of density (σ_t) along 158° W., January 15 - 26, 1951. Contour interval 0.2 g/l. *Hugh M. Smith* cruise 8, stations 1-26.

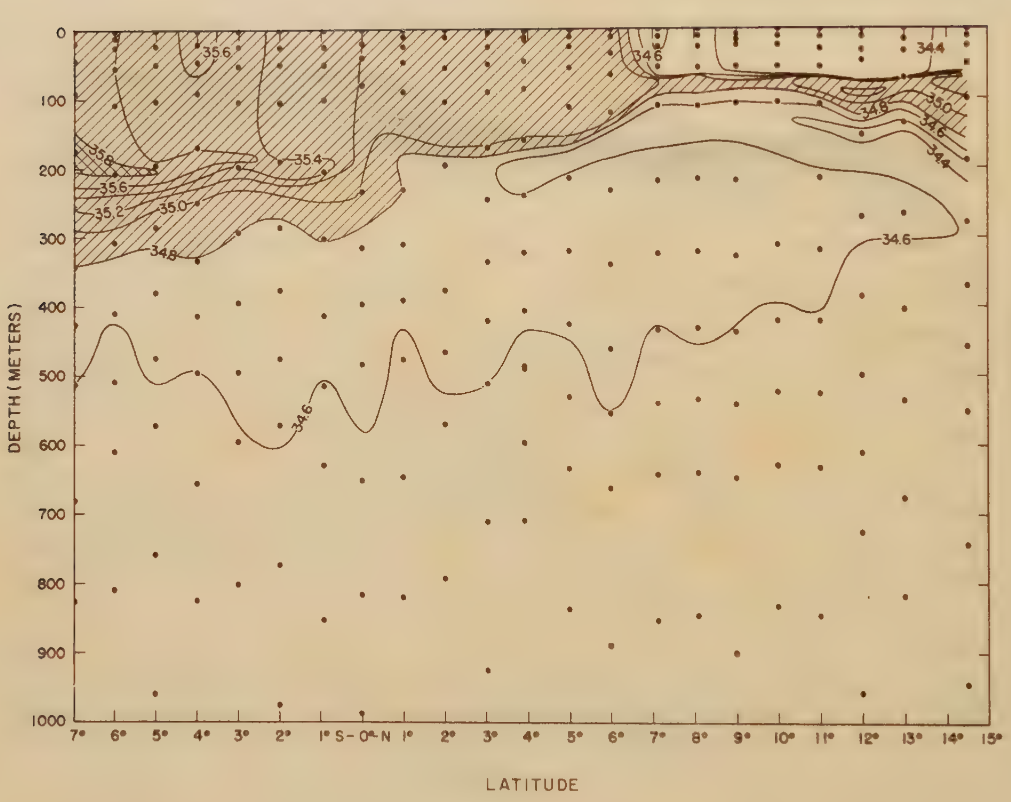

Fig. 18. -- Meridional salinity section along 158° W., January 15 - 26, 1951. Contour interval 0.2 °/oo. *Hugh M. Smith* cruise 8, stations 1-26.

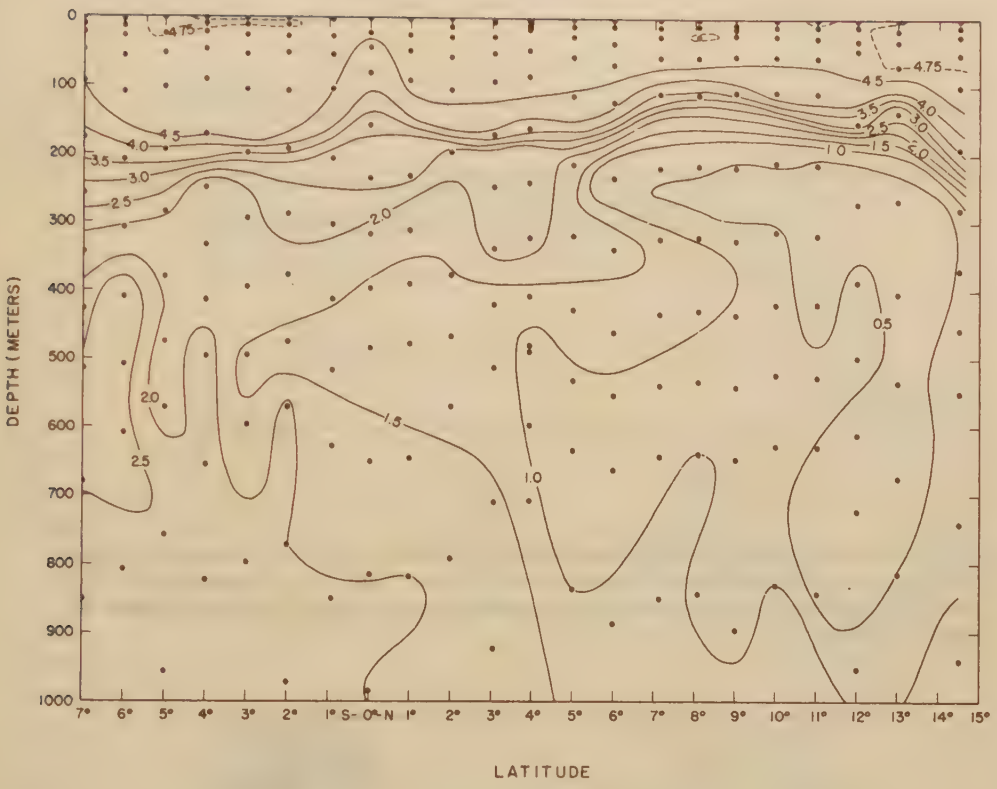

Fig. 19.-- Meridional section showing the concentration of dissolved oxygen along 158° W., January 15 - 26, 1951. Contour interval 0.5 ml/l. Hugh M. Smith cruise 8, stations 1-26.

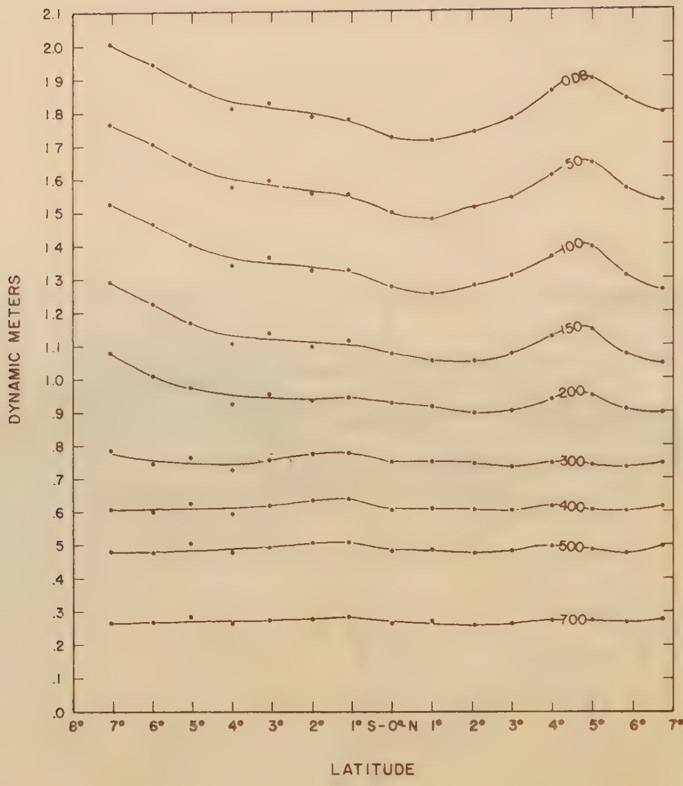

Fig. 20. -- Smoothed profiles of isobaric surfaces relative to the 1,000-decibar surface along a NNE-SSW line between 165° W. and 170° W., February 12 - 16, 1951. Points are the result of dynamic computations. Hugh M. Smith cruise 8, stations 62-76.

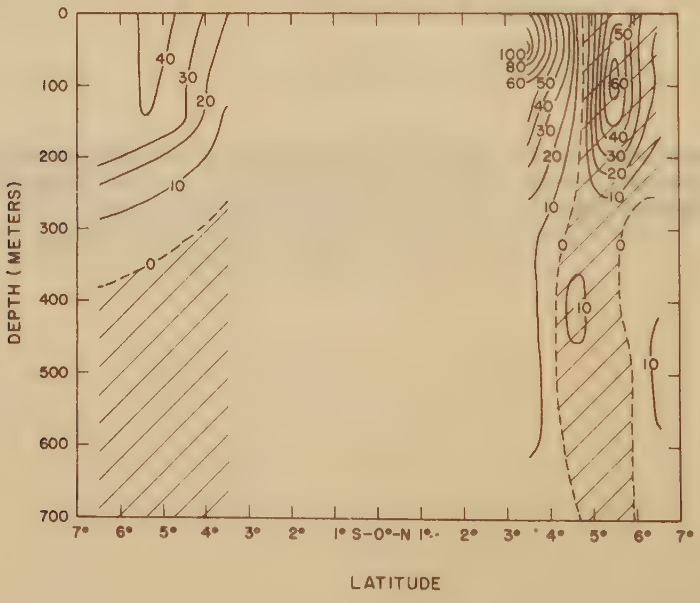

Fig. 21. -- Geostrophic currents across a NNE-SSW line between 165° W. and 170° W., February 12 - 16, 1951. Computations based on smoothed profiles of isobaric surfaces (fig. 20). Current magnitude in cm/sec. East-southeast currents hatched. Hugh M. Smith cruise 8, stations 62-76.

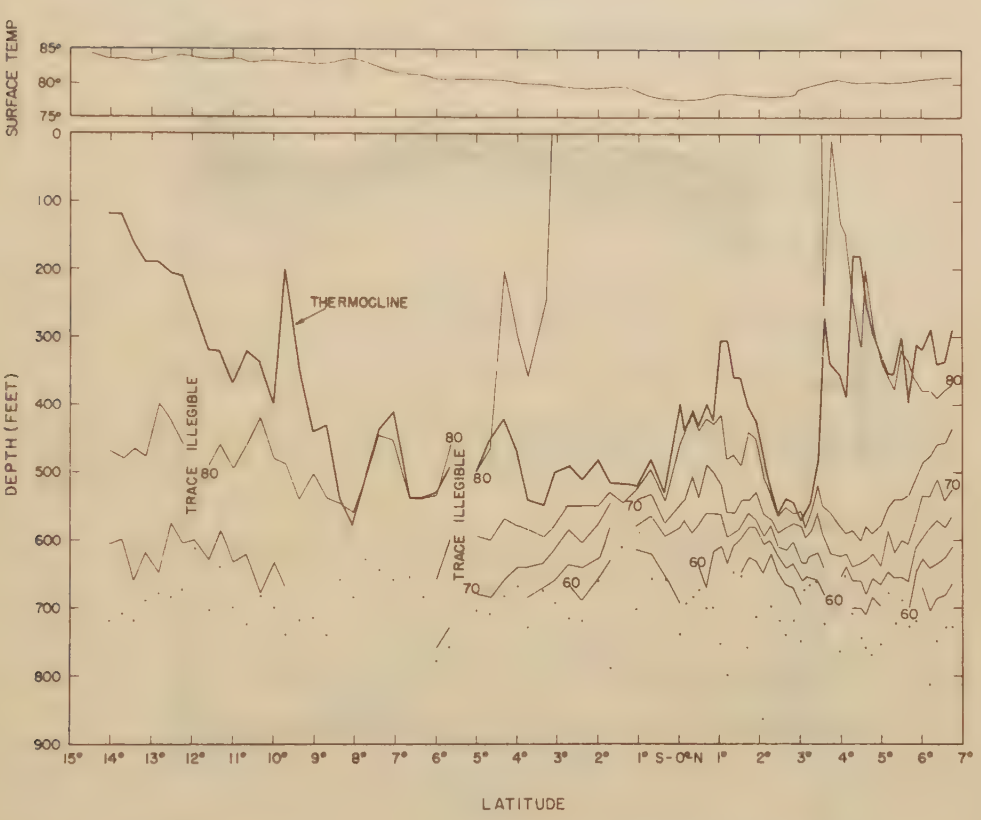

Fig. 22.-- Above, surface temperature and below, temperature section based on bathythermograph data along a NNE-SSW line between 165° W. and 172° W., February 12-18, 1951. Isotherms drawn at intervals of 5° F. Dots indicate depths of observations. *Hugh M. Smith* cruise 8.

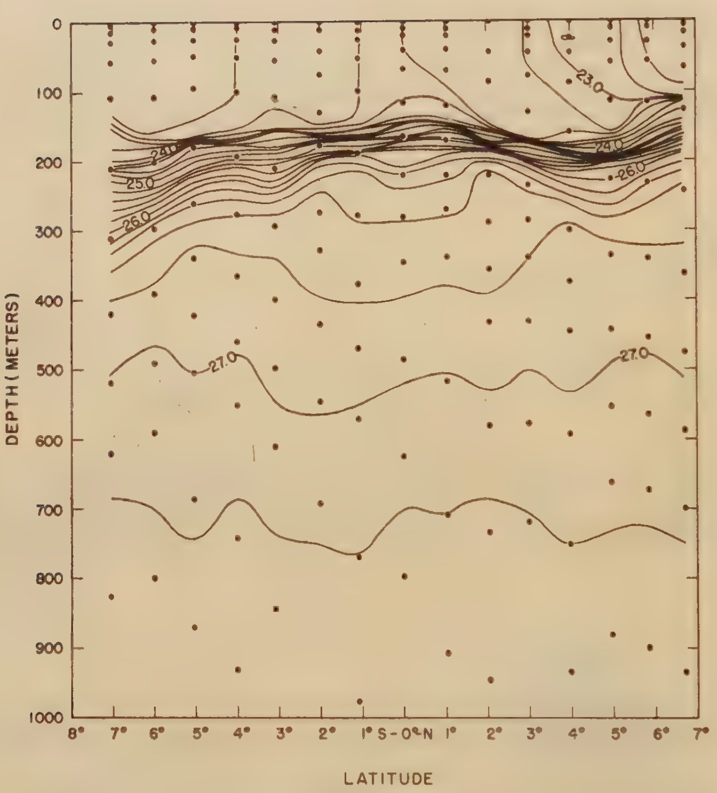

Fig. 23.-- Section showing the distribution of density (σ_t) along a NNE-SSW line between 165° W. and 170° W., February 12 - 16, 1951. Contour interval 0.2 g/l. *Hugh M. Smith* cruise 8, stations 62-76.

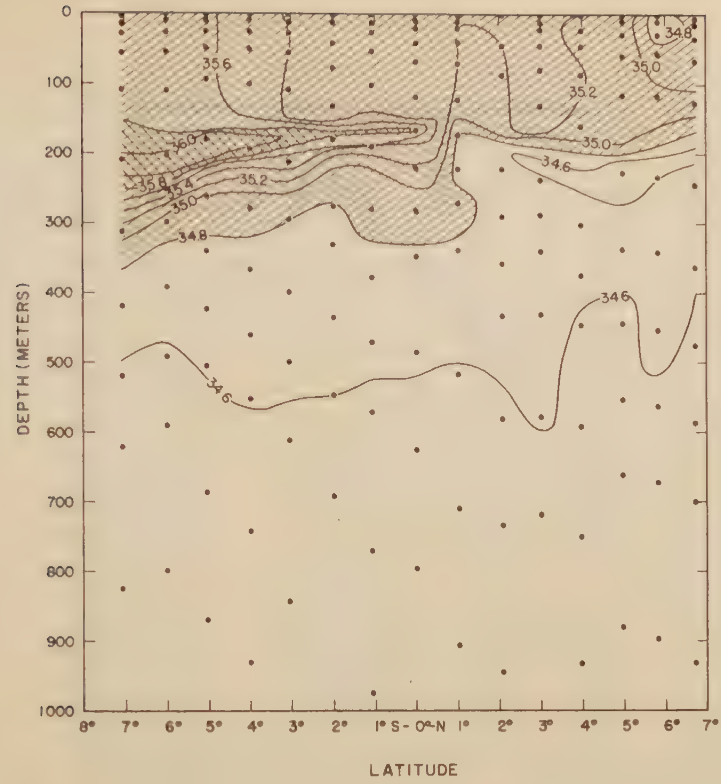

Fig. 24.-- Salinity section along a NNE-SSW line between 165° W. and 170° W., February 12 - 16, 1951. Contour interval 0.2 °/oo. Hugh M. Smith cruise 8, stations 62-76.

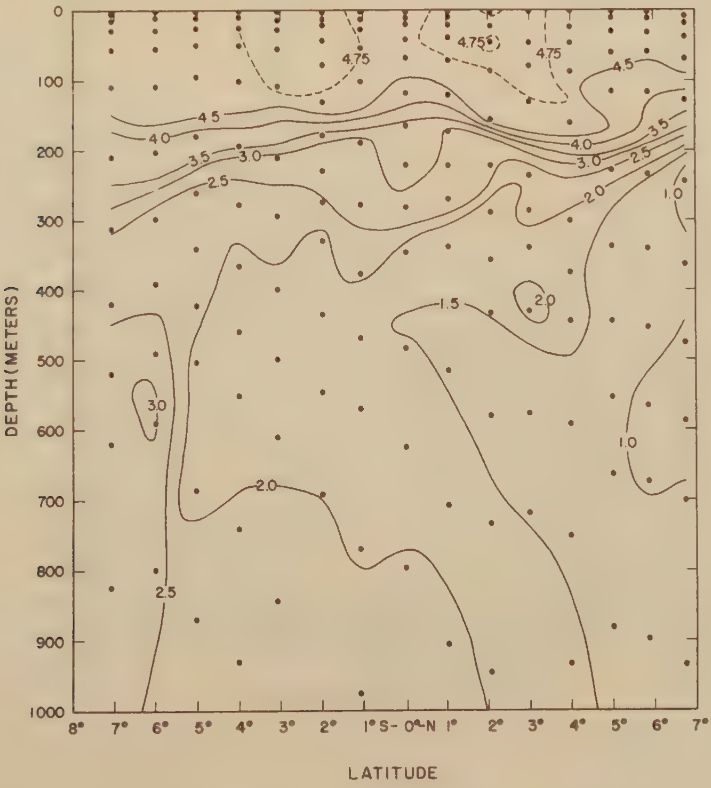

Fig. 25.-- Section showing the concentration of dissolved oxygen along a NNE-SSW line between 165° W. and 170° W., February 12 - 16, 1951. Contour interval 0.5 ml/l. Hugh M. Smith cruise 8, stations 62-76.

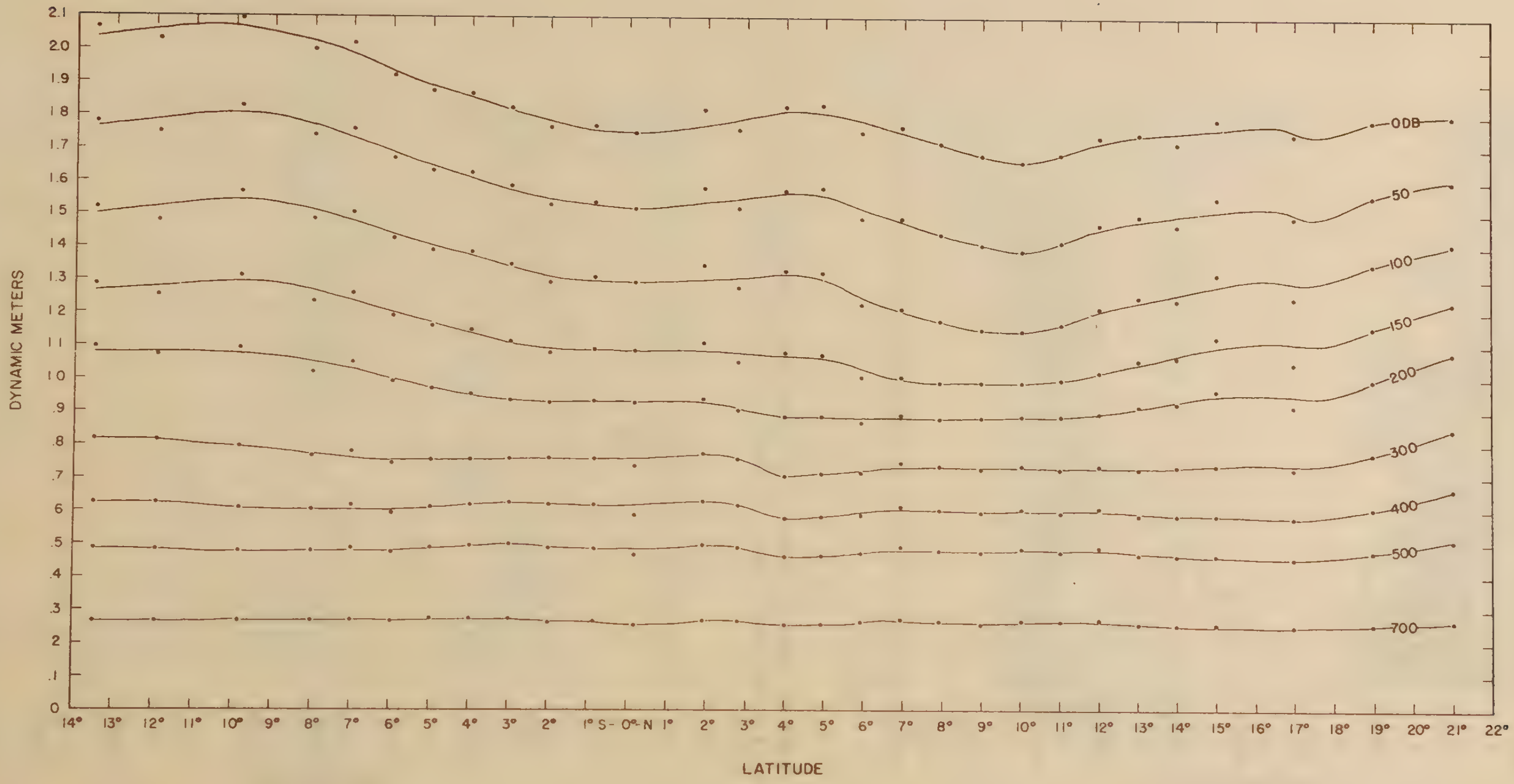

Fig. 26.--Smoothed profiles of isobaric surfaces relative to the 1,000-decibar surface along 172° W., February 27 - March 12, 1951. Points are the result of dynamic computations. Hugh M. Smith cruise 8, stations 77-106.

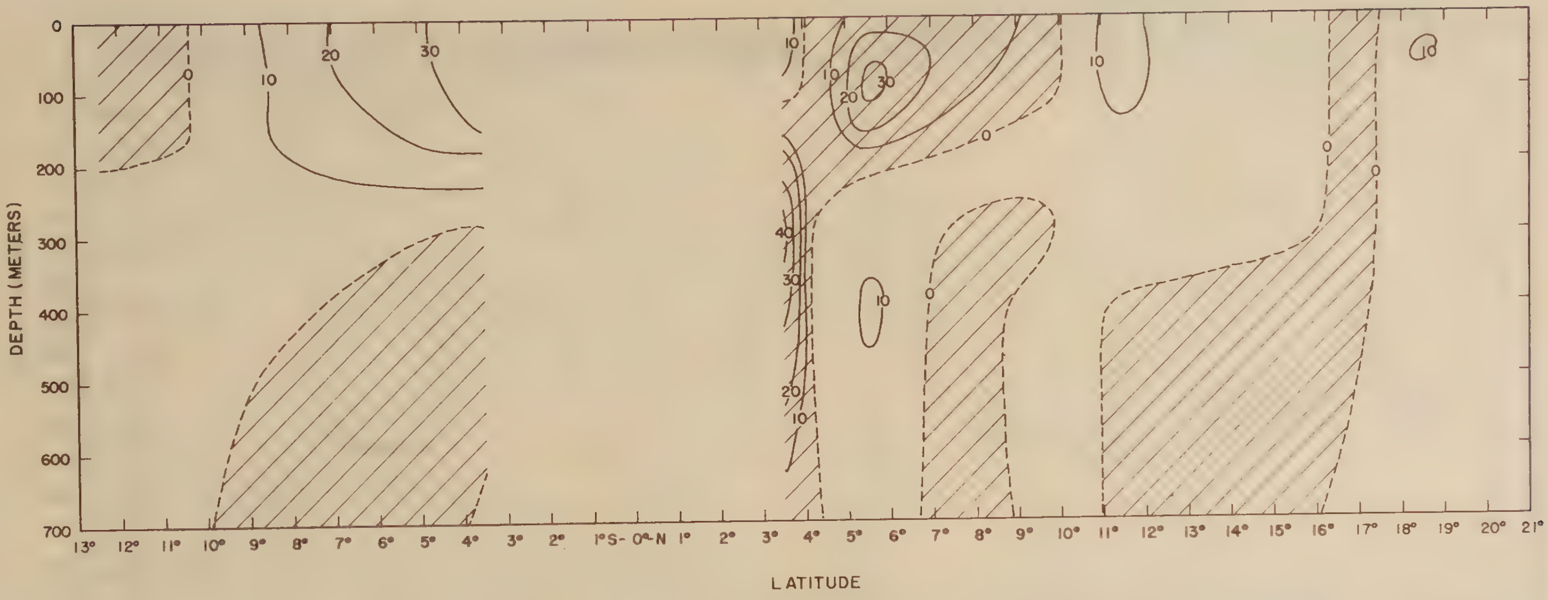

Fig. 27.-- Zonal components of the geostrophic currents across 172° W., February 27 - March 12, 1951. Computations based on smoothed profiles of isobaric surfaces (fig. 26). Current magnitude in cm/sec. East currents hatched. Hugh M. Smith cruise 8, stations 77-106.

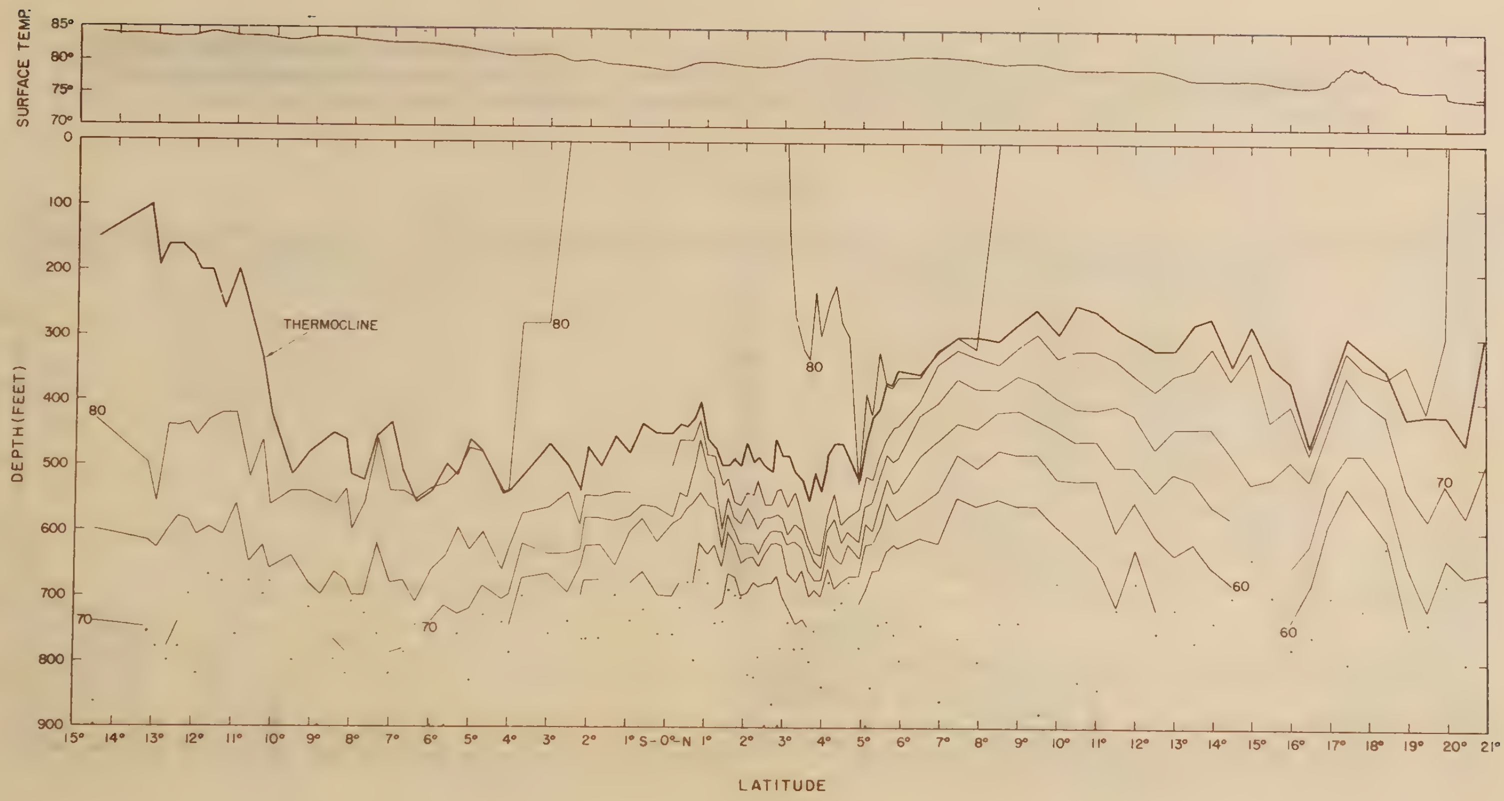

Fig. 28.-- Above, surface temperature and below, temperature section based on bathythermograph data along 172° W., February 27 - March 12, 1951. Isotherms drawn at intervals of 5° F. Dots indicate depths of observations. *Hugh M. Smith* cruise 8.

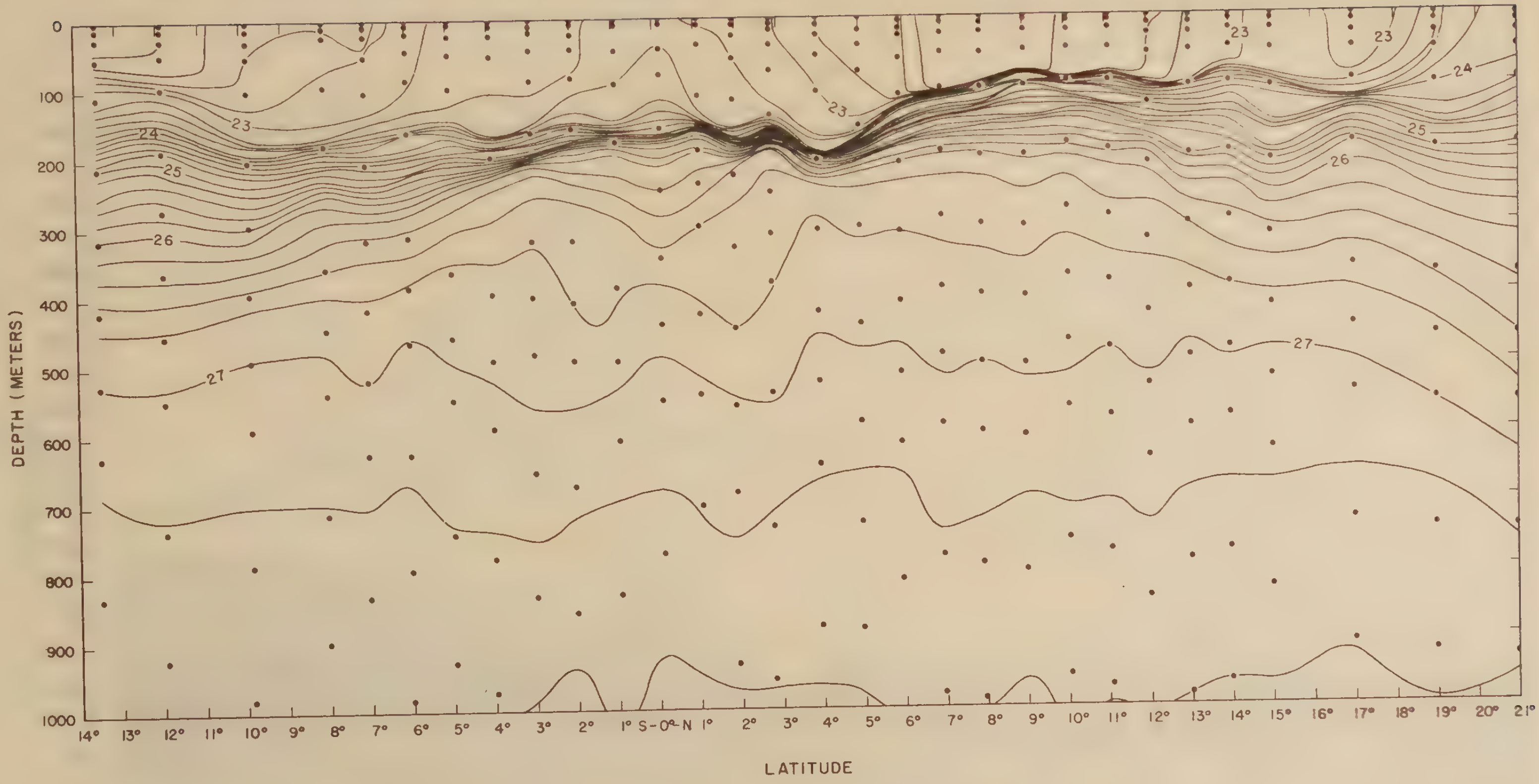

Fig. 29.-- Meridional section showing the distribution of density (σ_t) along 172° W., February 27 - March 12, 1951. Contour interval 0.2 °/oo . Hugh M. Smith cruise 8, stations 77-106.

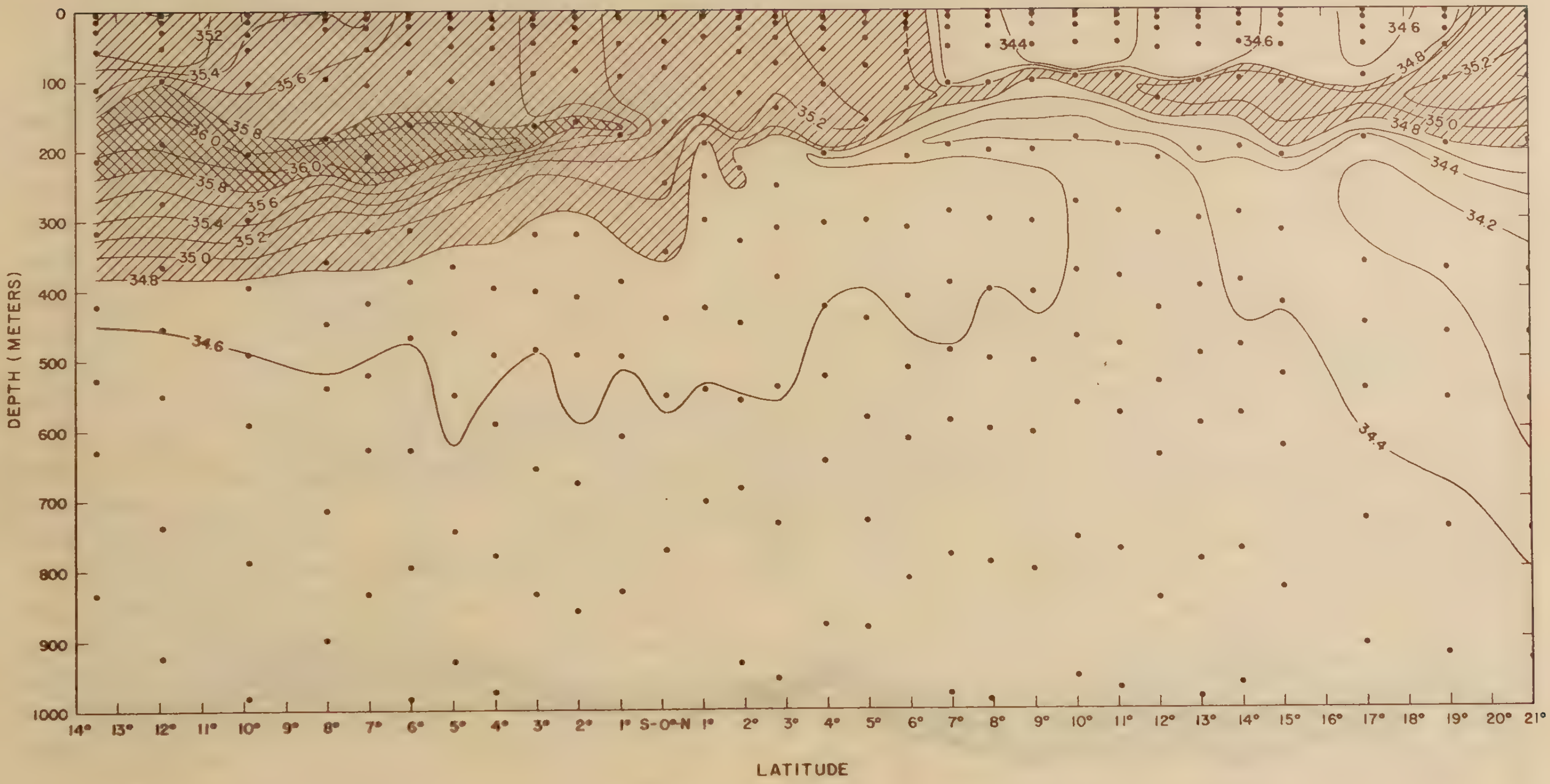

Fig. 30. -- Meridional salinity section along 172° W., February 27 - March 12, 1951. Contour interval 0.2 °/oo. Hugh M. Smith cruise 8, stations 77-106.

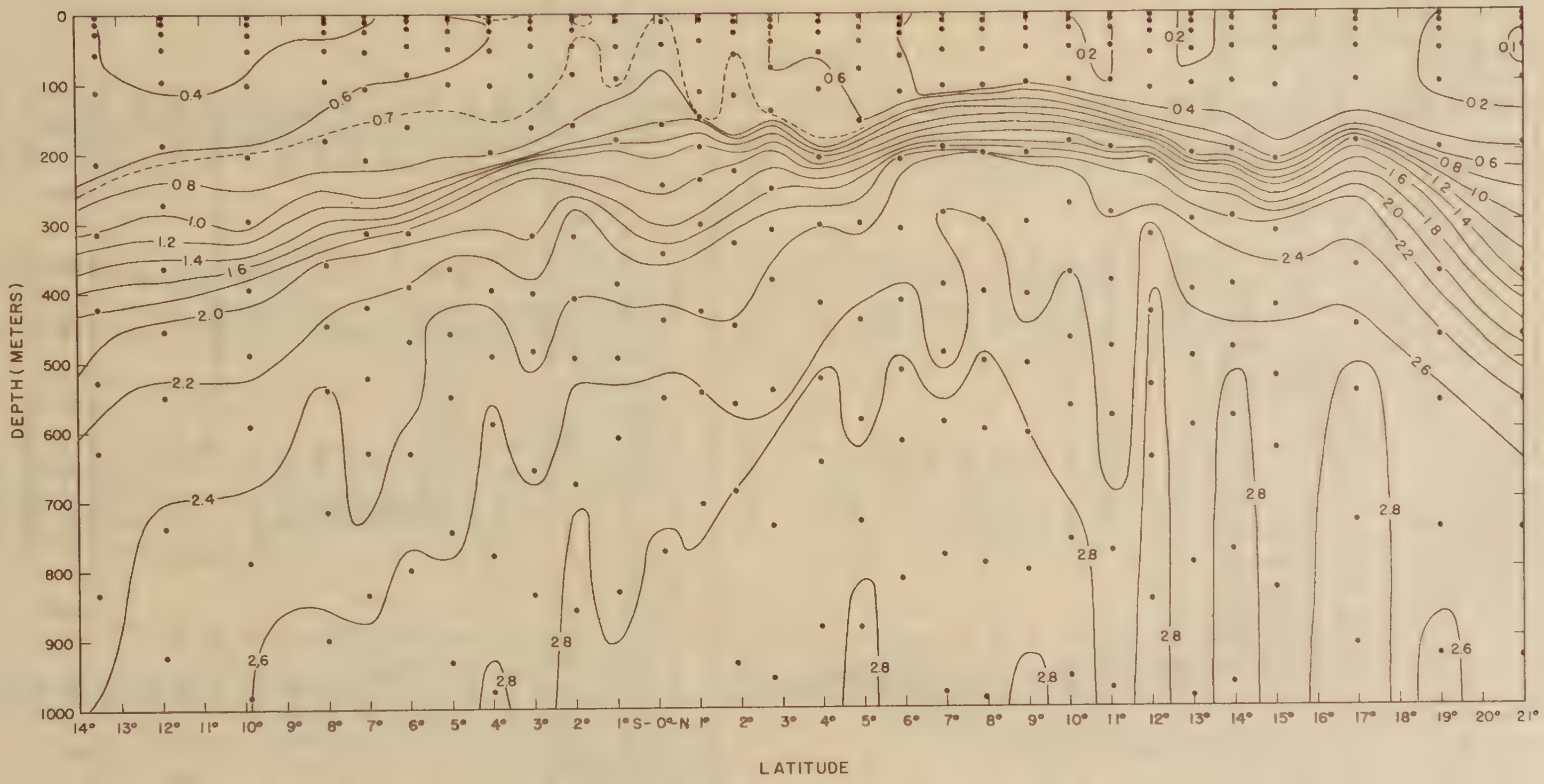

Fig. 31. -- Meridional section showing the concentration of inorganic phosphate along 172° W., February 27 - March 12, 1951. Contour interval 0.2 μg at/l. Hugh M. Smith cruise 8, stations 77-106.

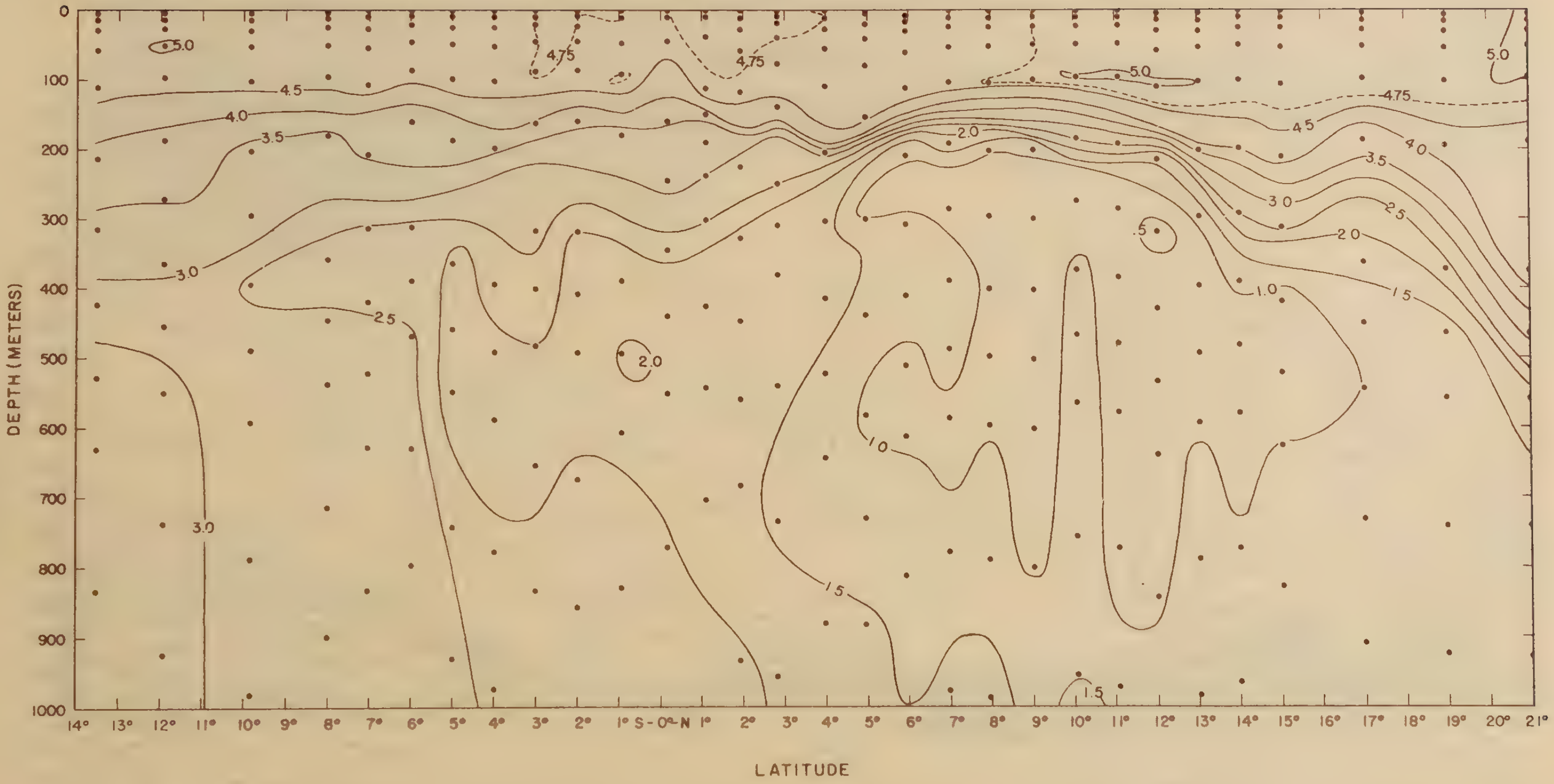

Fig. 32. -- Meridional section showing the concentration of dissolved oxygen along 172° W., February 27 - March 12, 1951. Contour interval 0.5 ml/l. *Hugh M. Smith* cruise 8, stations 77-106.

STATION 1

M/V *Hugh M. Smith*: Cruise 5, 27°00'N, 175°11'W, June 30, 1950. Messenger time: 1955 GCT. Weather: scattered clouds, cumulus and altostratus. Wind: 050°, 14 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	24.80	35.46	23.77	4.89	0.34
09	25.12	35.46	23.67	4.86	0.42
09					0.22
46	24.11	35.43	23.95	5.03	0.23
91	1/	35.17		5.24	0.24
182	16.52	34.67	25.39	4.96	0.43
274	13.98	34.49	25.81	4.98	0.77
365	12.09	34.34	26.08	4.99	0.91
551	08.06	34.05	26.54	4.18	1.67
738	05.09	34.05	26.93	2.03	2.56
926	03.93	34.23	27.20	0.90	2.86
1114	03.32	34.38	27.38	1.07	3.00
1114					2.65
1402	02.69	34.45	27.49	1.54	2.93

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	24.80	35.46	23.77	0.000	1.912
10	25.10	35.46	23.68	0.042	1.870
20	25.05	35.46	23.69	0.084	1.828
30	25.02	35.46	23.70	0.126	1.786
50	23.68	35.41	24.07	0.207	1.705
75	21.68	35.23	24.50	0.299	1.613
100	20.03	35.06	24.82	0.382	1.530
150	18.38	34.87	25.10	0.534	1.378
200	16.00	34.64	25.49	0.672	1.240
250	14.51	34.54	25.74	0.794	1.118
300	13.40	34.45	25.91	0.907	1.005
400	11.32	34.28	26.18	1.113	0.799
500	09.10	34.11	26.43	1.295	0.617
600	07.17	34.03	26.65	1.455	0.457
700	05.54	34.04	26.87	1.593	0.319
800	04.60	34.10	27.03	1.712	0.200
1000	03.67	34.30	27.29	1.912	0.000

1/ Thermometer was off scale.

STATION 2

M/V Hugh M. Smith: Cruise 5, 25°02'N, 174°10'W, July 1, 1950. Messenger time: 1312 GCT. Weather: overcast (with breaks), cumulus and cirrus. Wind: 100°, 14 kt. Sea: 3-5 ft. Wire angle: 0°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.94	22.98	4.85	0.26
10	26.30	34.92	22.90	4.71	0.25
50	25.43	35.32	23.47	5.13	0.13
100	23.16	35.37	24.19	5.13	0.81 1/
200	18.60	34.90	25.07	4.34	0.57
297	14.32	34.49	25.74	4.75	0.68
393	11.46	34.25	26.13	4.75	1.15
586	07.07	34.04	26.68	3.02	1.96
781	04.97	34.18	27.05	1.40	2.69
976	03.94	34.31	27.27	0.99	2.92
1171	03.20	34.40	27.41	1.43	2.80
1466	02.66	34.52	27.55	1.66	2.79

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.10	34.94	22.98	0.000	2.038
10	26.30	34.92	22.90	0.049	1.989
20	26.30	34.96	22.93	0.099	1.939
30	26.30	35.00	22.96	0.148	1.890
50	25.43	35.32	23.47	0.242	1.796
75	24.06	35.39	23.94	0.348	1.690
100	23.16	35.37	24.19	0.445	1.593
150	20.78	35.14	24.68	0.623	1.415
200	18.60	34.90	25.07	0.780	1.258
250	16.05	34.65	25.49	0.919	1.119
300	14.19	34.48	25.76	1.041	0.997
400	11.25	34.23	26.15	1.256	0.782
500	08.72	34.08	26.46	1.437	0.601
600	06.87	34.04	26.70	1.593	0.445
700	05.72	34.10	26.90	1.727	0.311
800	04.80	34.20	27.09	1.843	0.195
1000	03.84	34.32	27.28	2.038	0.000

1/ An anomalous value.

STATION 3

M/V *Hugh M. Smith*. Cruise 5, 22°58'N, 173°00'W, July 2, 1950. Messenger time: first cast, 0613 GCT; second cast, 0837 GCT. Weather: broken clouds, cumulus and cirrus. Wind: 090°, 13 kt. Sea: 3-5 ft. Wire angle: first cast, 20°; second cast, 05°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.10	34.94	22.98	4.69	0.33
09	26.32	34.92	22.89	4.67	0.22
47	26.24	34.92	22.92	4.86	0.26
94	23.65	35.19	23.91		0.32
186	20.52	34.58[1/]		5.06	0.39
276	15.69	34.63	25.55	4.73	0.61
366	12.04	34.31	26.07	4.80	0.96
366					1.21
545	07.34	34.05	26.64	2.83	2.05
723	05.06	34.16	27.03	1.56	2.61
902	04.34	34.34	27.25	1.05	2.82
1081	03.69	34.42	27.38	1.55	2.72
1351	03.04	34.52	27.52	1.60	2.76
1943	02.10	34.60	27.66	2.27	2.58
2443	01.71	34.63	27.72	2.68	2.02
2443					2.32
2943	01.56	34.54[1/]		2.91	2.16
3943	01.45	34.67	27.77	3.58	2.32

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.10	34.94	22.98	0.000	2.062
10	26.32	34.92	22.89	0.049	2.013
20	26.30	34.92	22.90	0.099	1.963
30	26.28	34.92	22.91	0.149	1.913
50	26.20	34.97	22.97	0.248	1.814
75	24.36	35.17	23.68	0.363	1.699
100	23.51	35.19	23.95	0.466	1.596
150	22.09	35.18	24.35	0.657	1.405
200	19.70	35.06	24.91	0.826	1.236
250	16.85	34.77	25.39	0.971	1.091
300	14.75	34.54	25.69	1.098	0.964
400	10.99	34.22	26.19	1.314	0.748
500	08.32	34.06	26.51	1.491	0.571
600	06.37	34.06	26.78	1.640	0.422
700	05.24	34.14	26.99	1.765	0.297
800	04.70	34.24	27.13	1.875	0.187
1000	03.97	34.39	27.33	2.062	0.000

[1/] Anomalous values.

STATION 4

M/V Hugh M. Smith: Cruise 5, 21°00'N, 172°00'W, July 3, 1950. Messenger time: 0232 GCT. Weather: overcast (with breaks), altocumulus and cirrus. Wind: 080°, 17 kt. Sea: 3-5 ft. Wire angle: 24°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.00	34.96	23.02	4.87	0.06
09	26.22	34.92	22.92	4.82	0.04
46	26.19	34.97	22.97	4.88	0.02
90	23.18	35.17	24.03	5.07	0.07
178	20.06	35.14	24.87	4.57	0.22
264	13.64	34.43	25.84	4.83	0.66
349	10.74	34.18	26.20	4.58	1.00
522	06.78	34.07	26.74	2.73	1.99
697	05.27	34.25	27.07	1.22	2.46
874	04.38	34.40	27.29	1.27	2.49
874					2.72
1053	03.85	34.49	27.42	1.46	2.47
1322	03.10	34.51	27.51	1.73	2.43

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.00	34.96	23.02	0.000	1.922
10	26.22	34.92	22.93	0.049	1.873
20	26.21	34.93	22.94	0.098	1.824
30	26.20	34.94	22.95	0.148	1.774
50	26.18	34.96	22.97	0.246	1.676
75	25.79	35.13	23.32	0.360	1.562
100	22.86	35.18	24.13	0.459	1.463
150	21.23	35.21	24.60	0.640	1.282
200	19.00	35.02	25.06	0.800	1.122
250	14.62	34.52	25.70	0.933	0.989
300	12.40	34.32	26.00	1.045	0.877
400	09.40	34.09	26.36	1.237	0.685
500	07.12	34.05	26.63	1.397	0.525
600	06.00	34.15	26.90	1.531	0.391
700	05.26	34.26	27.03	1.646	0.276
800	04.72	34.34	27.21	1.748	0.174
1000	03.93	34.47	27.39	1.922	0.000

STATION 5

M/V Hugh M. Smith: Cruise 5, 19°00'N, 171°52'W, July 3, 1950. Messenger time: 1829 GCT. Weather: broken clouds, cumulus, altocumulus and cirrus. Wind: 080°, 18 kt. Sea: <1 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	34.74	22.73	4.34	0.38
08	26.52	34.63	22.61	4.81	0.26
41	26.52	34.63	22.61	4.70	0.22
41					0.66 1/
82	24.73	34.96	23.41	5.10	0.22
163	20.54	35.10	24.71	4.48	0.38
239	15.92	34.65	25.52	4.44	0.61
310	11.95	34.27	26.05	4.47	1.12
453	07.07	34.27	26.77	1.84	2.46
614	05.85	34.27	27.02	1.19	2.81
614					3.14 1/
773	05.06	34.40	27.21	1.25	2.99
773					3.33 1/
939	04.39	34.47	27.35	1.42	2.92
1203	03.50	34.52	27.47	1.52	3.08

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.40	34.74	22.73	0.000	1.929
10	26.52	34.63	22.61	0.052	1.877
20	26.52	34.63	22.61	0.104	1.825
30	26.52	34.63	22.61	0.157	1.772
50	26.50	34.64	22.63	0.262	1.667
75	25.12	34.91	23.26	0.386	1.543
100	24.02	35.04	23.69	0.497	1.432
150	21.40	35.14	24.51	0.691	1.238
200	18.85	34.94	25.03	0.853	1.076
250	15.00	34.56	25.65	0.989	0.940
300	12.42	34.31	25.99	1.102	0.827
400	09.07	34.26	26.55	1.285	0.644
500	07.03	34.26	26.85	1.428	0.501
600	05.96	34.26	26.99	1.550	0.379
700	05.43	34.34	27.12	1.659	0.270
800	04.94	34.41	27.24	1.757	0.172
1000	04.14	34.49	27.39	1.929	0.000

1/ Anomalous values.

STATION 6

M/V Hugh M. Smith: Cruise 5, 17°01'N, 171°46'W, July 4, 1950. Messenger time: 1040 GCT. Weather: scattered clouds, no observation. Wind: 100°, 10 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26•30	34•54	22•61	4•82	0•35
09	26•42	34•54	22•57	4•76	0•28
47	26•40	34•54	22•58	4•83	0•27
94	25•20	34•67	23•05	4•97	0•26
186	20•78	34•92	24•51	4•58	0•48
271	13•09	34•38	25•91	3•47	1•15
353	09•68	34•23	26•43	2•62	1•91
523	06•70	34•34	26•96	1•10	2•57
701	05•63	34•45	27•19	1•06	2•67
883	04•75	34•47	27•31	1•14	2•62
883					2•38 1/
1067	04•02	34•54	27•44	1•33	2•17 1/
1067					2•41 1/
1346	03•28	34•54	27•51	1•59	2•72

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26•30	34•54	22•61	0•000	1•964
10	26•42	34•54	22•58	0•053	1•911
20	26•42	34•54	22•58	0•105	1•859
30	26•40	34•54	22•58	0•158	1•806
50	26•40	34•54	22•58	0•264	1•700
75	26•40	34•54	22•58	0•397	1•567
100	24•80	34•73	23•22	0•522	1•442
150	22•70	34•94	23•99	0•739	1•225
200	19•92	34•88	24•71	0•921	1•043
250	14•78	34•52	25•67	1•064	0•900
300	11•60	34•28	26•12	1•173	0•791
400	08•52	34•26	26•63	1•346	0•618
500	06•99	34•33	26•91	1•481	0•483
600	06•14	34•40	27•08	1•596	0•368
700	05•66	34•45	27•18	1•699	0•265
800	05•14	34•46	27•25	1•794	0•170
1000	04•27	34•53	27•41	1•964	0•000

1/ Anomalous values.

STATION 7

M/V Hugh M. Smith: Cruise 5, 15°00'N, 171°54'W, July 5, 1950. Messenger time: first cast, 0138 GCT; second cast, 0241 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 19 kt. Sea: 3-5 ft. Wire angle: first cast, 24°; second cast, 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	34.56	22.50	4.80	0.37
09	26.75	34.56	22.49	4.73	0.31
46	26.57	34.54	22.53	4.78	0.33
90	26.53	34.56	22.56	4.78	0.30
175	19.44	34.87	24.83	4.26	0.59
257	12.72	34.34	25.96	3.30	1.43
339	09.60	34.25	26.45	2.63	2.04
511	06.84	34.43	27.01	0.78	2.99
690	05.65	34.45	27.18	0.90	3.11
874	04.77	34.52	27.34	1.01	3.18
1059	04.16	34.52	27.41		3.13
1300	03.38	34.54	27.50	1.55	3.10
1771	02.17	34.58	27.64	2.18	2.81
2247	01.94	34.61	27.68	2.59	2.68
2734	01.70	34.63	27.72	2.90	2.64

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.70	34.56	22.50	0.000	1.917
10	26.74	34.56	22.49	0.054	1.863
20	26.68	34.56	22.51	0.107	1.810
30	26.61	34.55	22.52	0.161	1.756
50	26.56	34.54	22.53	0.267	1.650
75	26.53	34.55	22.55	0.401	1.516
100	26.52	34.56	22.56	0.534	1.383
150	22.70	34.94	23.99	0.767	1.150
200	16.75	34.66	25.33	0.934	0.983
250	13.00	34.36	25.92	1.056	0.861
300	10.97	34.26	26.22	1.157	0.760
400	08.36	34.34	26.72	1.321	0.596
500	06.98	34.43	26.99	1.448	0.469
600	06.13	34.44	27.12	1.558	0.359
700	05.58	34.46	27.20	1.658	0.259
800	05.05	34.50	27.29	1.750	0.167
1000	04.33	34.52	27.39	1.917	0.000

STATION 8

M/V *Hugh M. Smith*: Cruise 5, $14^{\circ}00'$N, $171^{\circ}57'$W, July 5, 1950. Messenger time: 1140 GCT. Weather: broken clouds, no observation. Wind: 100°, 19 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T ($^{\circ}$C)	S ($^{\circ}$/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.30	34.54	22.61	4.81	0.28
08	26.52	34.52	22.54	4.76	0.26
42	26.53	34.52	22.53	4.83	0.25
84	25.36	34.74	23.06	4.95	0.20
169	18.94	34.88	24.96	4.26	0.46
254	11.95	34.29	26.07	3.53	1.26
341	09.22	34.34	26.59	1.64	2.14
516	07.28	34.43	26.95	0.81	2.56
692	05.84	34.47	27.18	0.96	2.72
870	05.14	34.47	27.26	1.09	2.76
1052	04.42	34.49	27.36	1.25	2.70
1333	03.53	34.52	27.47	1.60	2.68

INTERPOLATED AND CALCULATED					
DEPTH (m)	T ($^{\circ}$C)	S ($^{\circ}$/oo)	σ t (gm/l)	ΔD (dyn. m)	ΔD1000-ΔD (dyn. m)
00	26.30	34.54	22.61	0.000	1.856
10	26.52	34.52	22.53	0.053	1.803
20	26.52	34.52	22.53	0.106	1.750
30	26.52	34.52	22.53	0.159	1.697
50	26.53	34.52	22.53	0.266	1.590
75	26.50	34.52	22.54	0.400	1.456
100	24.04	34.88	23.56	0.522	1.334
150	20.55	34.94	24.59	0.716	1.140
200	16.41	34.66	25.41	0.867	0.989
250	12.20	34.30	26.03	0.985	0.871
300	10.10	34.34	26.44	1.078	0.778
400	08.52	34.38	26.73	1.231	0.625
500	07.44	34.43	26.93	1.361	0.495
600	06.55	34.46	27.08	1.476	0.380
700	05.80	34.47	27.18	1.579	0.277
800	05.37	34.47	27.23	1.676	0.180
1000	04.66	34.48	27.32	1.856	0.000

STATION 9

M/V Hugh M. Smith: Cruise 5, 13°00'N, 172°01'W, July 5, 1950. Messenger time: 2015 GCT. Weather overcast (with breaks), cumulus and altocumulus. Wind 070°, 19 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	34.65	22.73	4.82	0.40
09	26.42	34.61	22.63	4.75	0.32
42	26.42	34.61	22.63	4.79	0.30
83	26.43	34.61	22.63	4.79	0.31
162	19.22	34.83	24.85	4.30	0.53
239	11.80	34.38	26.16	2.30	1.81
317	09.46	34.49	26.66	0.94	2.51
481	07.60	34.49	26.95	0.92	2.84
651	06.21	34.51	27.16	0.84	3.02
819	05.18	34.51	27.29	1.19	3.00
991	04.48	34.51	27.37	1.31	2.98
1263	03.66	34.56	27.49	1.60	3.05

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	ΔD 1000-ΔD (Dyn. m)
00	26.20	34.65	22.73	0.000	1.814
10	26.42	34.61	22.63	0.052	1.762
20	26.42	34.61	22.63	0.104	1.710
30	26.42	34.61	22.63	0.157	1.657
50	26.42	34.61	22.63	0.261	1.553
75	26.43	34.61	22.63	0.393	1.421
100	25.86	34.67	22.85	0.522	1.292
150	20.54	34.90	24.56	0.734	1.080
200	15.47	34.54	25.53	0.883	0.931
250	11.35	34.42	26.28	0.991	0.823
300	09.79	34.49	26.61	1.074	0.740
400	08.34	34.49	26.84	1.213	0.601
500	07.43	34.49	26.98	1.336	0.478
600	06.64	34.50	27.10	1.448	0.366
700	05.88	34.51	27.20	1.550	0.264
800	05.26	34.51	27.28	1.643	0.171
1000	04.44	34.51	27.37	1.814	0.000

STATION 10

M/V Hugh M. Smith: Cruise 5, 12°00'N, 172°00'W, July 6, 1950. Messenger time: 0435 GCT. Weather: broken clouds, cumulus, altocumulus and cirrus. Wind: 070°, 21 kt. Sea: 3-5 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	34.60	22.57	4.76	0.32
08	26.82	34.60	22.50	4.73	0.27
38	26.76	34.58	22.50	4.75	0.28
76	26.14	34.63	22.73	4.32	0.30
152	16.21	34.60	25.41	3.70	0.86
228	11.14	34.47	26.35	1.21	2.00
304	09.90	34.61	26.68	0.71	2.41
458	07.88	34.56	26.97	0.72	2.47
614	06.64	34.52	27.11	0.81	2.73
774	05.48	34.52	27.26	0.90	2.79
940	04.73	34.54	27.36	1.04	2.72
1205	03.80	34.56	27.48	1.40	2.83

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.60	34.60	22.57	0.000	1.696
10	26.81	34.60	22.50	0.053	1.643
20	26.79	34.59	22.50	0.107	1.589
30	26.78	34.58	22.49	0.160	1.536
50	26.65	34.58	22.53	0.268	1.428
75	26.15	34.63	22.73	0.399	1.297
100	22.80	34.93	23.96	0.513	1.183
150	16.78	34.65	25.32	0.681	1.015
200	12.65	34.37	25.99	0.801	0.895
250	10.67	34.55	26.50	0.892	0.804
300	09.96	34.61	26.67	0.968	0.728
400	08.59	34.59	26.88	1.103	0.593
500	07.46	34.55	27.02	1.222	0.474
600	06.78	34.53	27.10	1.332	0.364
700	06.00	34.52	27.19	1.434	0.262
800	05.32	34.52	27.28	1.527	0.169
1000	04.43	34.55	27.40	1.696	0.000

STATION 11

M/V *Hugh M. Smith*: Cruise 5, 11°03'N, 172°03'W, July 6, 1950. Messenger time: 1324 GCT. Weather: overcast (with breaks), no observation. Wind: 060°, 20 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	34.65	22.54	4.75	0.34
09	27.04	34.63	22.45	4.69	0.27
42	27.10	34.67	22.46	4.71	0.25
82	26.99	34.69	22.51	4.69	0.26
159	15.91	34.58	25.46	3.70	0.88
234	10.66	34.40	26.39	1.63	2.15
309	09.32	34.58	26.76	0.60	2.54
460	07.63	34.56	27.00	0.61	2.82
610	06.26	34.51	27.15	0.90	2.95
763	05.28	34.52	27.28	1.11	2.91
921	04.62	34.52	27.36	1.58	2.87
1187	03.82	34.56	27.48	1.70	2.93

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.80	34.65	22.54	0.000	1.706
10	27.04	34.63	22.45	0.054	1.652
20	27.06	34.64	22.45	0.108	1.598
30	27.08	34.65	22.45	0.162	1.544
50	27.08	34.68	22.47	0.270	1.436
75	27.01	34.68	22.50	0.405	1.301
100	25.06	34.83	23.22	0.531	1.175
150	16.80	34.65	25.31	0.716	0.990
200	12.50	34.37	26.02	0.835	0.871
250	10.28	34.50	26.53	0.926	0.780
300	09.42	34.58	26.74	0.999	0.707
400	08.30	34.57	26.91	1.129	0.577
500	07.27	34.54	27.04	1.246	0.460
600	06.37	34.51	27.14	1.352	0.354
700	05.63	34.52	27.24	1.449	0.257
800	05.12	34.52	27.30	1.539	0.167
1000	04.36	34.53	27.40	1.706	0.000

STATION 12

M/V Hugh M. Smith: Cruise 5, 09°54'N, 172°02'W, July 6, 1950. Messenger time: 2230 GCT. Weather: overcast (with breaks), cumulus and stratocumulus. Wind: light and variable, 4 kt. Sea: < 1 ft. Wire angle: 03°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	34.56	22.47	4.75	0.44
10	27.12	34.60	22.40	4.69	0.46
50	27.10	34.63	22.43	4.73	0.42
98	20.06	34.94	24.72	4.73	0.53
196	11.37	34.61	26.42	0.81	2.16
292	09.80	34.67	26.75	0.52	2.53
388	08.86	34.61	26.85	0.54	2.72
581	06.78	34.51	27.08	0.88	2.94
581					2.67
775	05.44	34.51	27.26	0.87	3.12
971	04.48	34.52	27.37	1.25	3.03
971					2.77
1168	03.74	34.54	27.47	1.53	2.71
1466	03.08	34.56	27.55	2.01	2.79
1466					2.43

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	ΔD 1000-ΔD (dyn. m)
00	26.80	34.56	22.47	0.000	1.609
10	27.12	34.60	22.40	0.054	1.555
20	27.12	34.61	22.41	0.109	1.501
30	27.11	34.62	22.42	0.163	1.446
50	27.10	34.63	22.43	0.272	1.337
75	25.20	34.81	23.16	0.399	1.210
100	19.98	34.93	24.73	0.500	1.110
150	12.90	34.40	25.97	0.634	0.975
200	11.30	34.62	26.44	0.728	0.882
250	10.42	34.69	26.66	0.805	0.804
300	09.72	34.66	26.75	0.876	0.734
400	08.72	34.60	26.87	1.008	0.601
500	07.59	34.54	26.99	1.130	0.480
600	06.60	34.51	27.11	1.241	0.368
700	05.91	34.51	27.20	1.343	0.267
800	05.32	34.51	27.27	1.437	0.172
1000	04.38	34.52	27.39	1.609	0.000

STATION 13

M/V Hugh M. Smith: Cruise 5, 08°54'N, 172°00'W, July 7, 1950. Messenger time: 0636 GCT. Weather: overcast (with breaks), no observation. Wind: 180°, 12 kt. Sea: 0. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.90	34.27	22.22	4.75	0.47
09	27.45	34.27	22.05	4.68	0.35
46	27.35	34.45	22.21	4.75	0.34
91	22.54	34.81	23.94	4.86	0.42
181	11.06	34.49	26.39	1.28	2.27
271	09.98	34.63	26.69	0.54	2.63
362	09.02	34.58	26.81	0.46	2.80
543	07.34	34.52	27.01	0.55	3.03
724	05.72	34.49	27.21	0.83	3.17
907	04.73	34.56	27.38	1.13	3.17
1092	04.04	34.54	27.44	1.36	3.14
1374	03.20	34.54	27.52	1.56	2.90

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.90	34.27	22.22	0.000	1.637
10	27.45	34.27	22.05	0.057	1.580
20	27.42	34.33	22.10	0.115	1.522
30	27.39	34.37	22.14	0.172	1.465
50	27.32	34.46	22.23	0.285	1.352
75	26.60	34.59	22.56	0.422	1.215
100	20.36	34.83	24.46	0.533	1.104
150	12.21	34.41	26.11	0.669	0.968
200	10.80	34.57	26.50	0.753	0.879
250	10.19	34.64	26.66	0.834	0.803
300	09.66	34.62	26.73	0.905	0.732
400	08.68	34.57	26.85	1.038	0.599
500	07.73	34.54	26.97	1.161	0.476
600	06.81	34.50	27.07	1.274	0.363
700	05.91	34.49	27.18	1.378	0.259
800	05.23	34.53	27.30	1.471	0.166
1000	04.38	34.55	27.41	1.637	0.000

STATION 14

M/V Hugh M. Smith: Cruise 5, 08°00'N, 171°58'W, July 7, 1950. Messenger time: 1412 GCT. Weather: overcast (with breaks), no observation. Wind: calm. Sea: 0. Wire angle: 04°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.90	34.14	22.12	4.75	0.27
10	27.21	34.18	22.06	4.71	0.20
50	27.23	34.20	22.06	4.78	0.21
99	18.70	34.78	24.95	3.89	0.61
197	10.76	34.61	26.53	0.61	2.14
293	09.79	34.65	26.73	0.55	2.34
390	08.87	34.65	26.88	0.56	2.38
582	06.70	34.51	27.10	0.68	2.65
776	05.39	34.51	27.26	0.82	2.52
968	04.45	34.56	27.41	1.27	2.56
1161	03.72	34.56	27.49	1.48	2.56
1453	02.98	34.56	27.56	1.54	2.44

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	ΔD 1000-ΔD (dyn. m)
00	26.90	34.14	22.12	0.000	1.592
10	27.21	34.18	22.06	0.057	1.535
20	27.21	34.18	22.06	0.115	1.477
30	27.22	34.19	22.06	0.173	1.419
50	27.23	34.20	22.06	0.289	1.303
75	24.95	34.64	23.11	0.421	1.171
100	18.68	34.77	24.95	0.519	1.073
150	11.93	34.47	26.21	0.642	0.950
200	10.66	34.61	26.55	0.727	0.865
250	10.20	34.64	26.66	0.801	0.791
300	09.68	34.65	26.75	0.872	0.720
400	08.80	34.64	26.89	1.002	0.590
500	07.62	34.56	27.01	1.122	0.470
600	06.55	34.50	27.11	1.232	0.360
700	05.82	34.49	27.19	1.333	0.259
800	05.24	34.52	27.29	1.427	0.165
1000	04.34	34.56	27.42	1.592	0.000

STATION 15

M/V Hugh M. Smith: Cruise 5, 06°59'N, 171°46'W, July 7, 1950. Messenger time: 2250 GCT. Weather: broken clouds, cumulus, altostratus and cirrocumulus. Wind: negligible. Sea: < 1 ft. Wire angle: 27°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.20	34.33	21.85	4.71	0.43
09	27.20	34.27	22.13	4.67	0.37
44	27.18	34.34	22.18	4.71	0.34
87	23.81	34.70	23.49	4.93	0.38
172	11.92	34.52	26.25	1.31	2.17
255	09.86	34.65	26.72	0.89	2.52
338	09.09	34.63	26.83	0.81	2.68
506	07.62	34.60	27.04	0.97	2.88
677	06.24	34.56	27.20	1.09	3.09
851	05.12	34.56	27.33	1.36	3.02
1026	04.37	34.58	27.43	1.57	3.02
1299	03.42	34.58	27.53	1.67	3.14

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.20	34.33	21.85	0.000	1.606
10	27.20	34.28	22.13	0.058	1.548
20	27.19	34.31	22.16	0.115	1.491
30	27.18	34.32	22.17	0.172	1.434
50	27.12	34.36	22.22	0.285	1.321
75	26.20	34.49	22.61	0.422	1.184
100	21.02	34.82	24.37	0.533	1.073
150	14.35	34.55	25.78	0.679	0.927
200	11.07	34.60	26.47	0.776	0.830
250	09.96	34.64	26.70	0.852	0.754
300	09.41	34.63	26.78	0.921	0.685
400	08.57	34.63	26.92	1.036	0.570
500	07.70	34.60	27.02	1.141	0.465
600	06.85	34.57	27.12	1.250	0.356
700	06.07	34.56	27.22	1.350	0.256
800	05.40	34.56	27.30	1.442	0.164
1000	04.43	34.58	27.43	1.606	0.000

STATION 16

M/V Hugh M. Smith: Cruise 5, 06°02'N, 171°56'W, July 8, 1950. Messenger time: 0719 GCT. Weather: broken clouds, no observation. Wind: calm. Sea: 0. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.20	34.81	22.21	4.73	0.22
09	27.72	34.72	22.30	4.63	0.27
43	27.74	34.97	22.48	4.66	0.35
85	26.40	34.99	22.92	4.30	0.40
165	12.68	34.54	26.12	1.79	1.71
245	10.07	34.69	26.72	0.77	2.22
325	09.41	34.67	26.81	1.06	2.16
485	08.12	34.58	26.95	0.88	2.46
649	06.53	34.52	27.13	0.99	2.49
818	05.26	34.54	27.30	1.33	2.75
994	04.44	34.54	27.40	1.54	2.70
1273	03.48	34.60	27.54	1.92	2.69

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.20	34.81	22.21	0.000	1.651
10	27.72	34.72	22.30	0.056	1.595
20	27.73	34.80	22.35	0.111	1.540
30	27.74	34.88	22.41	0.166	1.485
50	27.71	34.98	22.50	0.274	1.377
75	27.40	34.99	22.60	0.407	1.244
100	23.20	34.94	23.85	0.525	1.126
150	13.70	34.55	25.92	0.681	0.970
200	11.10	34.65	26.50	0.773	0.878
250	10.03	34.68	26.72	0.848	0.803
300	09.60	34.67	26.78	0.916	0.735
400	08.83	34.62	26.87	1.046	0.605
500	08.00	34.57	26.96	1.169	0.482
600	07.07	34.54	27.07	1.284	0.367
700	06.14	34.53	27.18	1.388	0.263
800	05.38	34.54	27.29	1.482	0.169
1000	04.45	34.54	27.39	1.651	0.000

STATION 17

M/V Hugh M. Smith: Cruise 5, 05°00'N, 172°02'W, July 8, 1950. Messenger time: first cast, 1700 GCT; second cast, 1817 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: calm. Sea: 0. Wire angle: first cast, 0°; second cast, 0°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.80	34.70	22.26	4.55	0.35
10	27.90	34.70	22.22	4.67	0.33
50	27.78	34.74	22.29	4.69	0.34
100	26.30	35.21	23.12	4.05	0.72
198	11.14	34.65	26.50	0.85	2.43
294	09.04	34.65	26.86	1.70	2.51
389	08.46	34.63	26.93	1.73	2.51
581	07.22	34.58	27.08	1.30	2.87
772	05.74	34.52	27.23	1.38	3.07
965	04.51	34.54	27.39	1.54	3.10
1160	03.81	34.56	27.48	1.79	3.07
1469	03.08	34.56	27.55	2.03	3.00
1955	02.37	34.61	27.65	2.36	2.81
2441	01.90	34.65	27.72	2.72	2.52
2926	01.69	34.65	27.74	3.05	2.55
3413	01.56	34.61	27.71	3.10	2.58

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.80	34.70	22.26	0.000	1.706
10	27.90	34.70	22.22	0.056	1.650
20	27.85	34.72	22.25	0.112	1.594
30	27.82	34.72	22.26	0.168	1.538
50	27.78	34.74	22.29	0.280	1.426
75	27.40	35.14	22.72	0.414	1.292
100	26.30	35.21	23.12	0.539	1.167
150	18.19	34.77	25.07	0.733	0.973
200	11.02	34.65	26.52	0.846	0.860
250	09.80	34.66	26.74	0.919	0.787
300	09.01	34.65	26.86	0.984	0.722
400	08.42	34.62	26.93	1.108	0.598
500	07.73	34.61	27.03	1.224	0.482
600	07.08	34.57	27.09	1.334	0.372
700	06.30	34.53	27.16	1.438	0.268
800	05.57	34.52	27.25	1.535	0.171
1000	04.35	34.55	27.41	1.706	0.000

STATION 18

M/V Hugh M. Smith: Cruise 5, 04°00'N, 172°03'W, July 9, 1950. Messenger time: 0324 GCT. Weather: scattered clouds, cumulus. Wind: 020°, 9 kt. Sea: < 1 ft. Wire angle: 0°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.90	35.07	22.50	4.71	0.49
10	27.98	35.05	22.46	4.69	0.44
50	27.78	35.12	22.58	4.71	0.44
99	27.62	35.16	22.66	4.53	0.48
197	12.09	34.65	26.32	1.45	1.94
294	09.42	34.67	26.81	2.06	2.14
390	08.34	34.61	26.93	2.04	2.26
583	06.66	34.58	27.16	1.22	2.75
775	05.38	34.52	27.27	1.71	2.74
968	04.55	34.54	27.38	1.95	2.75
1161	03.87	34.56	27.47	2.02	2.76
1452	03.04	34.58	27.57	2.09	2.87

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.90	35.07	22.50	0.000	1.713
10	27.98	35.05	22.46	0.054	1.659
20	27.93	35.08	22.50	0.108	1.605
30	27.85	35.10	22.54	0.161	1.552
50	27.78	35.12	22.58	0.267	1.446
75	27.70	35.14	22.62	0.399	1.314
100	27.62	35.16	22.66	0.531	1.182
150	20.40	34.89	24.59	0.747	0.966
200	11.80	34.68	26.40	0.874	0.839
250	09.98	34.71	26.75	0.950	0.763
300	09.35	34.66	26.82	1.017	0.696
400	08.20	34.61	26.96	1.141	0.572
500	07.30	34.60	27.08	1.254	0.459
600	06.54	34.57	27.16	1.357	0.356
700	05.82	34.54	27.23	1.454	0.259
800	05.25	34.52	27.29	1.545	0.168
1000	04.40	34.54	27.40	1.713	0.000

STATION 19

M/V Hugh M. Smith: Cruise 5, 03°00'N, 172°01'W, July 9, 1950. Messenger time: 1056 GCT. Weather: scattered clouds, no observation. Wind: 070°, 15 kt. Sea: < 1 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.70	1/		4.61	0.42
09	27.82			4.60	0.46
42	27.79			4.61	0.42
83	27.59			4.52	0.48
164	19.30			3.24	0.97
247	10.29			2.46	2.02
330	09.54			2.30	2.15
504	07.58			1.62	2.63
681	05.94			1.46	2.98
861	04.89			1.77	2.96
1044	04.24			1.93	2.88
1326	03.28			2.13	2.87

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	27.70				
10	27.81				
20	27.80				
30	27.80				
50	27.75				
75	27.63				
100	26.90				
150	22.70				
200	11.10				
250	10.28				
300	09.86				
400	08.75				
500	07.64				
600	06.65				
700	05.80				
800	05.24				
1000	04.42				

1/ Values available, but no bottle numbers.

STATION 20

M/V Hugh M. Smith: Cruise 5, 02°00'N, 171°53'W, July 9, 1950. Messenger time: 1903 GCT. Weather: scattered clouds, cumulus. Wind: 140°, 14 kt. Sea: < 1 ft. Wire angle: 42°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.40	35.08	22.67	4.71	0.42
08	27.70	35.05	22.55	4.69	0.36
36	27.60	35.10	22.62	4.68	0.40
72	27.26	35.32	22.90	4.72	0.52
146	22.79	35.05	24.06	3.40	0.82
221	11.60	34.85	26.56	2.89	1.67
300	10.56	34.79	26.71	1.80	2.03
464	07.77	34.61	27.02	1.97	2.35
640	06.46	34.56	27.17	1.84	2.57
822	04.98	34.54	27.34	2.14	2.59
1009	04.39	34.56	27.42	2.15	2.47
1294	03.54	34.56	27.50	2.35	2.49
1294					2.73

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.40	35.08	22.67	0.000	1.723
10	27.68	35.05	22.56	0.053	1.670
20	27.63	35.06	22.58	0.105	1.617
30	27.62	35.08	22.60	0.159	1.564
50	27.48	35.18	22.72	0.262	1.460
75	27.25	35.32	22.90	0.390	1.333
100	27.00	35.36	23.01	0.514	1.209
150	21.50	34.99	24.36	0.728	0.995
200	12.27	34.87	26.45	0.860	0.862
250	11.20	34.82	26.62	0.939	0.784
300	10.56	34.79	26.71	1.011	0.711
400	08.78	34.65	26.91	1.144	0.579
500	07.45	34.60	27.06	1.261	0.462
600	06.76	34.57	27.13	1.368	0.355
700	05.95	34.55	27.22	1.467	0.255
800	05.12	34.54	27.32	1.558	0.165
1000	04.40	34.56	27.42	1.723	0.000

STATION 21

M/V Hugh M. Smith: Cruise 5, 00°54'N, 172°10'W, July 10, 1950. Messenger time: 0407 GCT. Weather: scattered clouds, cumulus. Wind: 140°, 14 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.10	35.35	22.97	4.73	0.72
09	27.12	35.35	22.96	4.70	0.55
44	26.90	35.39	23.06	4.70	0.56
88	26.80	35.35	23.07	4.65	0.58
179	17.16	35.23	25.67	3.33	1.14
272	12.42	34.87	26.43	3.11	1.61
366	10.24	34.74	26.73	1.59	2.31
557	07.30	34.58	27.07	1.56	2.52
753	05.96	34.52	27.20	1.96	2.88
950	05.79 1/	34.54 1/	27.24	1.86	2.77
1150	04.34	34.56	27.42	2.04	2.93
1450	03.61	34.56	27.50	2.11	2.87

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.10	35.35	22.97	0.000	1.784
10	27.10	35.35	22.97	0.049	1.735
20	27.07	35.37	23.00	0.098	1.686
30	26.97	35.38	23.03	0.147	1.637
50	26.88	35.38	23.06	0.244	1.541
75	26.82	35.37	23.08	0.364	1.420
100	26.78	35.35	23.07	0.486	1.299
150	22.12	35.15	24.32	0.699	1.085
200	15.10	35.08	26.03	0.843	0.941
250	12.70	34.89	26.39	0.937	0.847
300	11.78	34.83	26.52	1.021	0.764
400	09.61	34.70	26.80	1.168	0.616
500	08.00	34.62	27.00	1.294	0.490
600	06.98	34.57	27.10	1.406	0.379
700	06.27	34.54	27.18	1.509	0.275
800	05.63	34.52	27.24	1.607	0.178
1000	04.75	34.55	27.37	1.724	0.000

1/ Looks improbable on Temperature-Depth and T-S curves. Bottom three bottles may have pretripped.

STATION 22

M/V *Hugh M. Smith*: Cruise 5, 00°08'S, 172°01'W, July 10, 1950. Messenger time: 1201 GCT. Weather: broken clouds, no observation. Wind: 160°, 11 kt. Sea: 1-3 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	35.37	23.08	4.75	0.47
09	26.87	35.37	23.06	4.69	0.54
44	26.64	35.37	23.13	4.65	0.52
88	26.21	35.41	23.29	4.48	0.58
173	19.10	35.34	25.27	3.13	0.96
272	12.63	34.90	26.41	3.17	1.43
367	10.54	34.74	26.67	1.75	2.06
561	07.35	34.52	27.01	1.81	2.35
756	06.06	34.51	27.18	1.84	2.54
951	04.82	34.49	27.32	2.09	2.51
951					2.76
1148	04.00	34.51	27.42	2.24	2.40
1430	03.08	34.58	27.56	2.24	2.46

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.80	35.37	23.08	0.000	1.807
10	26.86	35.37	23.06	0.048	1.759
20	26.84	35.37	23.07	0.096	1.711
30	26.79	35.37	23.08	0.144	1.663
50	26.61	35.38	23.15	0.240	1.567
75	26.36	35.41	23.25	0.358	1.449
100	26.13	35.41	23.32	0.474	1.333
150	22.12	35.18	24.34	0.680	1.127
200	16.60	35.19	25.77	0.829	0.978
250	13.60	34.96	26.26	0.932	0.875
300	12.01	34.85	26.49	1.019	0.788
400	09.90	34.69	26.75	1.169	0.638
500	08.17	34.55	26.92	1.301	0.506
600	07.02	34.52	27.06	1.418	0.389
700	06.40	34.52	27.14	1.525	0.282
800	05.79	34.50	27.21	1.625	0.182
1000	04.64	34.50	27.34	1.807	0.000

STATION 23

M/V Hugh M Smith: Cruise 5, 01°00'S, 171°57'W, July 10, 1950. Messenger time: 1950 GCT. Weather, scattered clouds, cumulus. Wind: 120°, 15 kt. Sea: 1-3 ft. Wire angle: 31°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.70	35.43	23.16	4.69	0.59
09	26.62	35.39	23.15	4.66	0.56
42	26.62	35.39	23.15	4.68	0.56
86	26.50	35.43	23.22	4.63	0.59
173	22.50	35.77	24.68	3.30	0.92
262	12.72	34.97	26.44	3.15	1.52
353	10.66	34.76	26.67	2.14	2.02
540	07.30	34.58	27.07	1.80	2.57
731	06.08	34.52	27.19	1.93	2.77
924	04.80	34.54	27.36	2.12	2.83
1118	04.13	34.58	27.46	2.24	2.81
1409	03.18	34.61	27.58	2.24	2.77

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	26.70	35.43	23.16	0.000	1.791
10	26.62	35.39	23.15	0.047	1.744
20	26.62	35.39	23.15	0.095	1.696
30	26.62	35.39	23.15	0.142	1.649
50	26.61	35.40	23.16	0.237	1.554
75	26.55	35.41	23.19	0.355	1.436
100	26.47	35.44	23.24	0.473	1.318
150	25.30	35.63	23.75	0.695	1.096
200	16.80	35.34	25.84	0.857	0.934
250	13.19	35.01	26.38	0.956	0.835
300	11.80	34.67	26.55	1.038	0.753
400	09.80	34.71	26.78	1.184	0.607
500	07.90	34.61	27.00	1.310	0.481
600	06.85	34.56	27.11	1.420	0.371
700	06.24	34.53	27.17	1.523	0.268
800	05.60	34.52	27.25	1.520	0.171
1000	04.47	34.56	27.41	1.791	0.000

STATION 24

M/V *Hugh M. Smith*: Cruise 5, 02°02'S, 171°57'W, July 11, 1950. Messenger time: 0200 GCT Weather scattered clouds, cumulus. Wind: 100°, 8 kt. Sea: <1 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.30	35.48	23.00	4.79	0.91
08	27.12	35.50	23.07	4.78	0.98
37	26.82	35.44	23.13	4.81	0.94
73	26.74	35.41	23.13	4.80	0.83
144	26.66	35.55	23.26	4.46	0.97
216	14.36	35.14	26.24	2.61	1.83
290	11.12	34.83	26.64	2.95	2.08
450	08.34	34.63	26.95	2.26	2.43
620	06.38	34.54	27.16	1.84	2.89
796	05.00	34.49	27.30	2.31	2.69
979	04.46	34.56	27.41	2.19	2.41
1266	03.56	34.56	27.50	2.24	2.82

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn m)	ΔD1000-ΔD (dyn. m)
00	27.30	35.48	23.00	0.000	1.778
10	27.11	35.49	23.07	0.048	1.730
20	26.99	35.48	23.10	0.096	1.682
30	26.88	35.46	23.12	0.144	1.634
50	26.80	35.42	23.12	0.240	1.538
75	26.73	35.42	23.14	0.359	1.419
100	26.72	35.48	23.19	0.478	1.300
150	26.60	35.57	23.30	0.712	1.066
200	16.90	35.38	25.85	0.884	0.894
250	12.07	34.92	26.53	0.979	0.799
300	10.95	34.82	26.66	1.055	0.723
400	09.12	34.69	26.88	1.191	0.587
500	07.63	34.56	27.00	1.312	0.466
600	06.57	34.51	27.11	1.421	0.357
700	05.63	34.48	27.21	1.522	0.256
800	04.99	34.49	27.29	1.613	0.165
1000	04.40	34.57	27.42	1.778	0.000

STATION 25

M/V Hugh M. Smith: Cruise 5, 02°59'S, 171°59'W, July 11, 1950. Messenger time: 1150 GCT. Weather: scattered clouds, cumulus. Wind: 110°, 16 kt. Sea: 1-3 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	35.50	23.21	4.64	0.64
09	27.03	35.48	23.09	4.64	0.62
46	27.00	35.48	23.10	4.69	0.58
92	26.94	35.48	23.12	4.67	0.60
182	24.08	35.97	24.37	3.65	0.82
271	10.94	34.83	26.67	2.12	2.06
361	09.40	34.69	26.83	2.09	2.25
544	07.30	34.58	27.07	1.76	2.61
729	05.56	34.51	27.24	2.32	2.79
915	04.68	34.51	27.35	2.37	2.91
1102	04.02	34.54	27.44	2.34	2.92
1305	03.26	34.69	27.63	2.35	2.36

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.70	35.50	23.21	0.000	1.805
10	27.03	35.48	23.09	0.047	1.758
20	27.02	35.48	23.09	0.095	1.710
30	27.02	35.48	23.09	0.143	1.662
50	27.00	35.48	23.10	0.239	1.566
75	26.96	35.48	23.11	0.359	1.446
100	26.92	35.48	23.13	0.479	1.326
150	26.80	35.51	23.19	0.718	1.087
200	19.95	35.71	25.33	0.905	0.900
250	12.00	34.93	26.55	1.012	0.793
300	10.35	34.78	26.74	1.085	0.720
400	08.92	34.67	26.89	1.216	0.589
500	07.76	34.60	27.02	1.335	0.470
600	06.78	34.54	27.11	1.445	0.360
700	05.78	34.51	27.21	1.546	0.259
800	05.12	34.51	27.29	1.637	0.168
1000	04.40	34.52	27.38	1.805	0.000

STATION 26

M/V Hugh M. Smith: Cruise 5, 04°05'S, 171°56'W, July 11, 1950. Messenger time: 2117 GCT. Weather: scattered clouds, cumulus. Wind: no observation. Sea: 1-3 ft. Wire angle: 15°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.60	35.79	23.14	4.69	0.56
09	27.61	35.71	23.07	4.64	0.51
48	27.60	35.71	23.08	4.68	0.56
95	27.58	35.71	23.08	4.67	0.56
189	23.03	36.09	24.77	3.63	0.80
281	11.66	34.88	26.53	2.03	1.88
371	09.50	34.70	26.82	1.87	2.27
553	07.20	34.58	27.08	1.53	2.53
736	05.46	34.54	27.28	2.17	2.72
918	04.50	34.54	27.39	2.27	2.67
1104	03.92	34.54	27.45	2.35	2.59
1394	03.18	34.60	27.57	2.32	2.66

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.60	35.79	23.14	0.000	1.810
10	27.61	35.71	23.08	0.048	1.762
20	27.60	35.71	23.08	0.096	1.714
30	27.60	35.71	23.08	0.144	1.666
50	27.60	35.71	23.08	0.240	1.570
75	27.59	35.71	23.08	0.361	1.449
100	27.57	35.72	23.10	0.481	1.329
150	26.55	35.81	23.49	0.714	1.096
200	22.00	35.99	24.99	0.902	0.908
250	12.98	35.01	26.42	1.020	0.790
300	11.10	34.84	26.65	1.099	0.711
400	09.07	34.68	26.88	1.235	0.575
500	07.80	34.61	27.02	1.355	0.455
600	06.70	34.56	27.13	1.463	0.347
700	05.78	34.56	27.25	1.561	0.249
800	05.04	34.54	27.33	1.649	0.161
1000	04.21	34.54	27.42	1.810	0.000

STATION 27

M/V Hugh M. Smith: Cruise 5, 05°04'S, 171°58'W, July 12, 1950. Messenger time: first cast, 0522 GCT; second cast, 0636 GCT. Weather: scattered clouds, no observation. Wind: 100°, 9 kt. Sea: 1-3 ft. Wire angle: first cast, 30°; second cast, 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.90	35.79	23.04	4.68	1/
09	27.86	35.70	22.99	4.64	
43	27.68	35.68	23.03	4.69	
85	27.66	35.70	23.05	4.67	
168	24.98	35.97	24.10	3.90	
247	15.10	35.19	26.12	2.36	
324	10.42	34.78	26.73	2.03	
480	08.14	34.63	26.98	1.73	
639	06.60	34.54	27.13	2.15	
806	05.29	34.51	27.28	2.52	
986	04.46	34.54	27.39	2.51	
1162 2/	03.87	35.21	27.99	3.30	
1611 3/	02.76	34.61	27.62	2.76	
2072	02.14	34.63	27.68	2.98	
2537	01.81	34.63	27.71	3.16	
3480	01.49	34.67	27.77	3.69	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.90	35.79	23.04	0.000	1.827
10	27.85	35.69	22.98	0.049	1.778
20	27.80	35.69	23.00	0.098	1.729
30	27.75	35.68	23.01	0.146	1.681
50	27.68	35.70	23.05	0.244	1.583
75	27.67	35.70	23.05	0.365	1.462
100	27.62	35.71	23.07	0.486	1.341
150	25.66	35.90	23.84	0.711	1.116
200	20.45	35.80	25.27	0.884	0.943
250	14.90	35.18	26.15	1.002	0.825
300	11.60	34.87	26.58	1.089	0.738
400	09.08	34.68	26.87	1.229	0.598
500	07.96	34.61	26.99	1.350	0.477
600	06.99	34.56	27.09	1.462	0.365
700	06.07	34.53	27.19	1.564	0.263
800	05.35	34.52	27.28	1.658	0.169
1000	04.40	34.54	27.40	1.827	0.000

1/ Photometer not operating properly.

2/ Only the temperature at this depth appears reasonable. Other values suggest that the Nansen bottle sample was contaminated through leakage on the way up.

3/ Depth not reliable.

STATION 28

M/V Hugh M. Smith: Cruise 5, 04°59'S, 158°03'W, July 28, 1950. Messenger time: first cast, 1349 GCT; second cast, 1449 GCT. Weather: broken clouds, cumulus. Wind: 110°, 14 kt. Sea: 3-5 ft. Wire angle: first cast, 35°; second cast, 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.60	35.68	23.38	4.67	1/
08	26.64	35.55	23.27	4.63	
41	26.67	35.55	23.26	4.71	
82	26.63	35.53	23.24	4.67	
155	21.76	36.06	25.11	3.73	
226	13.14	34.99	26.33	1.87	
300	10.82	34.81	26.68	2.00	
456	08.02	34.58	26.96	1.93	
622	06.76	34.54	27.11	2.00	
798	05.52	34.51	27.25	1.99	
985	04.22	34.54	27.42	2.28	
1274	03.36	34.65	27.59	2.63	
1756	02.46	34.63	27.66	2.74	
2237	02.05	34.65	27.71	2.93	
2718	01.80	34.67	27.74	3.10	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	ΔD (ml/l)	ΔD 1000-ΔD (µg at/l)
00	26.60	35.68	23.38	0.000	1.701
10	26.63	35.55	23.27	0.046	1.655
20	26.64	35.55	23.27	0.092	1.609
30	26.65	35.55	23.26	0.138	1.563
50	26.67	35.54	23.25	0.231	1.470
75	26.68	35.54	23.25	0.348	1.353
100	26.69	35.53	23.24	0.465	1.236
150	22.45	36.12	24.96	0.658	1.043
200	17.30	35.36	25.74	0.793	0.908
250	12.05	34.92	26.54	0.891	0.810
300	10.82	34.81	26.68	0.966	0.735
400	08.85	34.64	26.88	1.101	0.600
500	07.66	34.56	27.00	1.221	0.480
600	06.90	34.55	27.10	1.332	0.369
700	06.21	34.52	27.17	1.436	0.265
800	05.50	34.51	27.25	1.532	0.169
1000	04.16	34.54	27.43	1.701	0.000

1/ Photometer not operating properly.

STATION 29

M/V Hugh M. Smith, Cruise 5, 04°00'S, 158°03'W, July 29, 1950. Messenger time: 2350 GCT. Weather: broken clouds, cumulus. Wind: 110°, 19 kt. Sea: 3-5 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.20	35.48	23.35	4.81	1/
09	26.51	35.46	23.24	4.63	
40	26.44	35.44	23.25	4.70	
80	26.42	35.46	23.27	4.71	
158	23.86	36.08	24.52	3.83	
235	13.15	34.99	26.37	1.46	
312	10.31	34.81	26.77	1.25	
466	08.12	34.65	27.00	2.05	
621	06.54	34.56	27.16	1.76	
778	05.48	34.54	27.28	1.93	
940	04.67	34.54	27.37	2.07	
1205	03.78	34.58	27.49	2.23	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	26.20	35.48	23.35	0.000	1.722
10	26.50	35.46	23.24	0.046	1.676
20	26.46	35.45	23.25	0.092	1.629
30	26.45	35.44	23.24	0.139	1.583
50	26.43	35.44	23.25	0.232	1.490
75	26.42	35.45	23.26	0.348	1.373
100	26.41	35.46	23.27	0.465	1.256
150	24.35	36.01	24.32	0.674	1.047
200	18.75	35.56	25.53	0.830	0.891
250	11.81	34.90	26.57	0.933	0.789
300	10.52	34.83	26.75	1.006	0.716
400	08.98	34.71	26.91	1.137	0.585
500	07.71	34.63	27.05	1.254	0.468
600	06.70	34.57	27.14	1.361	0.360
700	05.92	34.54	27.22	1.460	0.261
800	05.33	34.54	27.29	1.553	0.169
1000	04.48	34.55	27.40	1.722	0.000

1/ Photometer not operating properly.

STATION 30

M/V Hugh M. Smith: Cruise 5, 03°03'S, 158°00'W, July 29, 1950. Messenger time: 0805 GCT. Weather: broken clouds, no observation. Wind: 100°, 21 kt. Sea: 3-5 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.30	35.48	23.32	4.75	1/
09	26.48	35.48	23.27	4.68	
38	26.50	35.48	23.26	4.70	
73	26.45	35.48	23.27	4.71	
146	21.90	35.93	24.97	3.63	
218	12.34	34.94	26.49	1.99	
290	10.08	34.74	26.75	2.12	
437	08.64	34.65	26.92	1.82	
592	07.10	34.60	27.11	1.33	
757	05.70	34.52	27.23	1.92	
930	04.86	34.51	27.32	2.06	
1210	03.73	34.58	27.50	2.34	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	35.48	23.32	0.000	1.659
10	26.48	35.48	23.27	0.046	1.613
20	26.48	35.48	23.27	0.092	1.567
30	26.50	35.48	23.26	0.139	1.520
50	26.48	35.48	23.27	0.231	1.428
75	26.44	35.49	23.29	0.347	1.312
100	26.43	35.49	23.29	0.463	1.196
150	21.75	35.91	25.00	0.655	1.004
200	13.65	35.03	26.30	0.775	0.884
250	11.28	34.84	26.62	0.857	0.802
300	09.92	34.73	26.77	0.928	0.731
400	08.93	34.67	26.89	1.057	0.602
500	08.04	34.63	27.00	1.178	0.481
600	07.02	34.59	27.11	1.288	0.371
700	06.12	34.54	27.20	1.390	0.269
800	05.42	34.52	27.27	1.484	0.175
1000	04.69	34.52	27.35	1.659	0.000

1/ Photometer not operating properly.

STATION 31

M/V Hugh M. Smith: Cruise 5, 02°03'S, 158°00'W, July 29, 1950. Messenger time: 1617GCT. Weather: broken clouds, cumulus. Wind: 080°, 18 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	35.53	23.33	4.65	1/
10	26.50	35.48	23.26	4.58	
47	26.52	35.48	23.25	4.64	
93	26.48	35.46	23.25	4.65	
183	13.57	35.07	26.35	2.29	
273	10.45	34.76	26.71	2.04	
362	09.88	34.72	26.77	1.75	
544	07.04	34.58	27.10	1.79	
730	06.05	34.52	27.19	1.88	
919	04.88	34.51	27.32	2.14	
1109	04.33	34.54	27.41	2.25	
1400	03.34	34.56	27.52	2.44	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.40	35.53	23.33	0.000	1.676
10	26.50	35.48	23.26	0.046	1.630
20	26.50	35.48	23.26	0.092	1.584
30	26.50	35.48	23.26	0.139	1.537
50	26.50	35.48	23.26	0.232	1.444
75	26.49	35.47	23.25	0.348	1.328
100	26.46	35.46	23.26	0.464	1.212
150	23.35	35.98	24.59	0.667	1.009
200	12.08	34.93	26.54	0.791	0.885
250	10.63	34.78	26.69	0.865	0.811
300	10.23	34.75	26.74	0.935	0.741
400	09.42	34.69	26.83	1.070	0.606
500	07.68	34.61	27.04	1.191	0.485
600	06.70	34.56	27.13	1.299	0.377
700	06.18	34.53	27.18	1.400	0.276
800	05.67	34.51	27.23	1.497	0.179
1000	04.65	34.52	27.36	1.676	0.000

1/ Photometer not operating properly.

STATION 32

M/V Hugh M. Smith: Cruise 5, 01°00'S, 158°01'W, July 30, 1950. Messenger time: 0047 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 22 kt. Sea: 5-8 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.30	35.48	23.32	4.70	1/
08	26.35	35.46	23.29	4.62	
42	26.30	35.48	23.32	4.66	
84	26.04	35.46	23.39	4.54	
169	16.20	35.32	25.96	2.63	
259	12.18	34.88	26.48	2.94	
351	10.71	34.79	26.68	1.73	
539	07.54	34.58	27.03	1.55	
728	06.24	34.52	27.16	1.70	
919	05.00	34.52	27.32	2.04	
1111	04.20	34.54	27.42	2.05	
1402	03.24	34.58	27.55	2.13	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	35.48	23.32	0.000	1.663
10	26.32	35.46	23.30	0.046	1.617
20	26.31	35.47	23.31	0.092	1.571
30	26.30	35.48	23.32	0.137	1.526
50	26.28	35.48	23.33	0.229	1.434
75	26.13	35.47	23.37	0.343	1.320
100	25.10	35.47	23.69	0.453	1.210
150	18.43	35.47	25.54	0.622	1.041
200	13.56	35.01	26.30	0.729	0.934
250	12.31	34.90	26.47	0.815	0.848
300	11.57	34.84	26.57	0.894	0.769
400	09.81	34.74	26.80	1.039	0.624
500	08.12	34.62	26.98	1.165	0.498
600	06.99	34.54	27.08	1.278	0.385
700	06.39	34.52	27.14	1.384	0.279
800	05.80	34.52	27.22	1.483	0.180
1000	04.71	34.53	27.36	1.663	0.000

1/ Photometer not operating properly.

STATION 33

M/V *Hugh M. Smith*: Cruise 5, 00°02'S, 157°58'W, July 30, 1950. Messenger time: 0850 GCT. Weather: scattered clouds, cumulus. Wind: 100°, 18 kt. Sea: 3-5 ft. Wire angle: 41°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.70	35.39	23.44	4.64	1/
03	25.84	35.37	23.38	4.58	
38	25.84	35.37	23.38	4.58	
76	25.70	35.37	23.43	4.48	
153	18.93	35.30	25.28	3.28	
237	12.81	34.92	26.39	3.12	
329	11.22	34.83	26.62	2.10	
518	07.72	34.61	27.03	1.57	
708	06.18	34.56	27.20	1.74	
897	05.25	34.52	27.29	1.99	
1088	04.16	34.54	27.43	2.04	
1378	03.20	34.63	27.59	2.11	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.70	35.39	23.44	0.000	1.679
10	25.84	35.37	23.38	0.045	1.634
20	25.83	35.37	23.39	0.090	1.589
30	25.84	35.37	23.38	0.135	1.544
50	25.81	35.37	23.39	0.226	1.453
75	25.70	35.37	23.43	0.338	1.341
100	25.42	35.35	23.50	0.450	1.229
150	19.00	35.29	25.26	0.630	1.049
200	15.05	35.10	26.06	0.750	0.929
250	12.50	34.90	26.43	0.842	0.837
300	11.62	34.86	26.57	0.923	0.756
400	09.87	34.73	26.78	1.068	0.611
500	08.00	34.62	27.00	1.194	0.485
600	06.95	34.58	27.12	1.304	0.375
700	06.21	34.56	27.20	1.405	0.274
800	05.70	34.53	27.24	1.501	0.178
1000	04.65	34.52	27.36	1.679	0.000

1/ Photometer not operating properly.

STATION 34

M/V Hugh M. Smith: Cruise 5, 00°57'N, 157°57'W, July 30, 1950. Messenger time: 1715 GCT. Weather: scattered clouds, cumulus. Wind: 100°, 17 kt. Sea: 3-5 ft. Wire angle: 45°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.50	35.21	23.37	4.56	1/
07	25.74	35.19	23.28	4.50	
34	25.75	35.17	23.26	4.52	
68	25.69	35.17	23.28	4.48	
137	20.12	34.90	24.67	3.22	
215	13.12	34.96	26.36	3.13	
299	10.85	34.83	26.69	2.01	
476	08.46	34.69	26.98	1.28	
659	06.38	34.58	27.19	1.63	
844	05.45	34.54	27.28	1.92	
1030	04.42	34.56	27.41	2.03	
1316	03.38	34.58	27.53	2.01	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.50	35.21	23.37	0.000	1.651
10	25.74	35.19	23.28	0.046	1.605
20	25.74	35.18	23.27	0.092	1.559
30	25.74	35.18	23.27	0.138	1.513
50	25.70	35.17	23.28	0.231	1.420
75	25.62	35.17	23.30	0.346	1.305
100	25.25	35.15	23.40	0.461	1.190
150	18.30	34.98	25.12	0.646	1.005
200	13.46	34.97	26.29	0.764	0.887
250	12.15	34.91	26.51	0.848	0.803
300	10.83	34.83	26.69	0.924	0.727
400	09.32	34.74	26.88	1.058	0.593
500	08.15	34.68	27.02	1.178	0.473
600	06.96	34.62	27.15	1.286	0.365
700	06.09	34.56	27.21	1.385	0.266
800	05.62	34.54	27.26	1.479	0.172
1000	04.55	34.56	27.40	1.651	0.000

1/ Photometer not operating properly.

STATION 35

M/V *Hugh M Smith* Cruise 5. 02°00'N, 158°07'W, July 31, 1950. Messenger time: 0158 GCT. Weather: broken clouds, cumulus. Wind: 110°, 17 kt. Sea: 3-5 ft. Wire angle: 37°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	35.28	23.17	4.67	0.72
07	26.42	35.23	23.10	4.58	0.69
37	26.21	35.21	23.15	4.56	0.69
73	26.09	35.23	23.20	4.51	0.76
147[1]	20.14	34.92	24.68	3.20	1.19
221	11.24	34.85	26.63	2.47	2.05
293	10.62	34.81	26.71	1.84	2.22
293					2.46
443	09.06	34.70	26.89	1.31	2.72
443					2.98
595	06.96	34.61	27.14	1.56	2.98
749	06.12	34.58	27.23	1.78	3.08
904	05.12	34.58	27.35	1.99	2.98
1144	04.10	34.60	27.48	2.09	3.07

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	26.30	35.28	23.17	0.000	1.652
10	26.39	35.22	23.10	0.047	1.605
20	26.32	35.21	23.11	0.095	1.557
30	26.26	35.21	23.13	0.143	1.509
50	26.18	35.22	23.16	0.238	1.414
75	26.05	35.23	23.21	0.356	1.296
100	25.81	35.22	23.28	0.473	1.179
150	18.25	34.86	25.12	0.661	0.991
200	11.88	34.87	26.53	0.773	0.879
250	11.00	34.83	26.66	0.848	0.804
300	10.55	34.80	26.72	0.919	0.733
400	09.55	34.73	26.84	1.055	0.597
500	08.25	34.66	26.99	1.178	0.474
600	06.91	34.60	27.14	1.288	0.364
700	06.34	34.59	27.21	1.388	0.264
800	05.82	34.58	27.27	1.483	0.169
1000	04.50	34.58	27.42	1.652	0.000

[1] Bottle may have pretripped.

STATION 36

M/V *Hugh M. Smith*: Cruise 5, 03°00'N, 157°58'W, July 31, 1950. Messenger time: 0932 GCT. Weather: scattered clouds, cumulus. Wind: 100°, 17 kt. Sea: 3-5 ft. Wire angle: 42°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.10	35.30	23.25	4.77	0.68
07	26.30	35.25	23.15	4.75	0.66
38	26.22	35.25	23.17	4.75	0.68
73	26.01	35.23	23.22	4.72	0.69
140	23.83	35.16	23.83	3.85	0.82
200	10.88	34.74	26.61	2.69	1.39
262	10.43	34.78	26.73	1.78	2.18
400	09.53	34.69	26.81	1.62	2.28
542	07.98	34.60	26.98	1.27	2.64
690	06.40	34.52	27.14	1.60	2.69
849	05.30	34.54	27.30	1.78	2.90
1114	04.00	34.56	27.46	1.86	2.87

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	26.10	35.30	23.25	0.000	1.733
10	26.29	35.25	23.15	0.047	1.686
20	26.27	35.25	23.16	0.094	1.639
30	26.23	35.25	23.17	0.142	1.592
50	26.14	35.24	23.19	0.236	1.497
75	26.00	35.23	23.23	0.353	1.380
100	25.92	35.22	23.25	0.471	1.262
150	23.62	35.09	23.84	0.692	1.041
200	10.88	34.74	26.61	0.833	0.900
250	10.43	34.73	26.73	0.905	0.829
300	10.31	34.78	26.75	0.974	0.759
400	09.53	34.69	26.81	1.110	0.623
500	08.44	34.63	26.93	1.238	0.495
600	07.31	34.56	27.05	1.356	0.378
700	06.30	34.52	27.16	1.463	0.270
800	05.60	34.53	27.25	1.561	0.172
1000	04.41	34.56	27.41	1.733	0.000

STATION 37

M/V *Hugh M. Smith*: Cruise 5, 04°02'N, 158°03'W, July 31, 1950. Messenger time: 1712 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 090°, 13 kt. Sea: 3-5 ft. Wire angle: 40°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.90	35.25	23.27	4.70	0.76
07	26.00	35.19	23.20	4.61	0.72
36	26.00	35.21	23.21	4.65	0.74
71	25.94	35.21	23.23	4.60	0.85
135	25.38	35.25	23.43	4.37	1.01
135					0.81
195	11.04	34.63	26.50	1.85	2.21
257	09.70	34.67	26.76	2.19	2.38
386	08.94	34.65	26.87	1.58	2.72
522	07.96	34.63	27.01	1.48	2.94
659	06.49	34.56	27.16	1.20	3.32
800	05.42	34.54	27.28	1.65	3.24
1042	04.40	34.54	27.40	1.84	3.28

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	25.90	35.25	23.27	0.000	1.705
10	26.00	35.20	23.21	0.046	1.659
20	26.00	35.20	23.21	0.093	1.612
30	26.00	35.20	23.21	0.140	1.565
50	25.99	35.21	23.22	0.234	1.471
75	25.90	35.21	23.24	0.351	1.354
100	25.71	35.24	23.33	0.467	1.238
150	25.23	35.25	23.48	0.694	1.011
200	10.57	34.68	26.62	0.842	0.863
250	09.72	34.67	26.76	0.913	0.792
300	09.50	34.66	26.79	0.980	0.725
400	08.86	34.65	26.89	1.109	0.596
500	08.11	34.64	27.00	1.229	0.476
600	07.07	34.59	27.11	1.340	0.365
700	06.14	34.55	27.20	1.442	0.263
800	05.42	34.54	27.28	1.535	0.170
1000	04.50	34.54	27.39	1.705	0.000

STATION 38

M/V *Hugh M. Smith*: Cruise 5, 05°00'N, 158°00'W, August 1, 1950. Messenger time: first cast, 0023 GCT; second cast, 0135 GCT; third cast, 0333 GCT. Weather: broken clouds, cumulus, stratocumulus and altocumulus. Wind: 130°, 16 kt. Sea: 1-3 ft. Wire angle: first cast, 25°; second cast, 32°; third cast, 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.20	35.23	22.85	4.69	0.53
08	27.30	35.14	22.75	4.68	0.48
46	27.12	35.14	22.81	4.70	0.49
85	26.30	35.16	23.08	4.63	0.64
169	20.75	34.90	24.50	3.44	0.82
253	10.08	34.70	26.72	0.86	2.41
336	09.04	34.65	26.86	1.95	2.41
507	07.92	34.61	27.00	1.35	2.73
507					2.28
681	06.49	34.56	27.16	1.06	2.85
861	05.20	34.54	27.31	1.10	3.05
1050	04.37	34.54	27.40	1.38	2.94
1244	03.70	34.56	27.49	1.69	2.84
1788	02.50	34.60	27.63	2.07	2.82
2271	02.00	34.65	27.71	2.85	2.68
2752	01.82	34.65	27.73	2.80	2.55
3715	01.44	34.65	27.75	3.61	2.27

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	27.20	35.23	22.85	0.000	1.784
10	27.29	35.14	22.75	0.051	1.733
20	27.24	35.14	22.77	0.102	1.682
30	27.19	35.14	22.78	0.153	1.631
50	27.11	35.14	22.79	0.254	1.530
75	26.85	35.15	22.90	0.381	1.403
100	25.95	35.17	23.20	0.502	1.282
150	23.05	35.05	23.98	0.721	1.063
200	16.00	34.70	25.54	0.885	0.899
250	10.10	34.70	26.72	0.983	0.801
300	09.38	34.67	26.82	1.051	0.733
400	08.60	34.63	26.91	1.178	0.606
500	07.96	34.61	26.99	1.297	0.487
600	07.15	34.58	27.09	1.410	0.374
700	06.31	34.56	27.19	1.514	0.270
800	05.58	34.54	27.26	1.610	0.174
1000	04.51	34.54	27.39	1.784	0.000

STATION 39

M/V Hugh M. Smith: Cruise 5, 06°00'N, 157°57'W, August 1, 1950. Messenger time: 1213 GCT. Weather: broken clouds, cumulus. Wind: 120°, 14 kt. Sea: 1-3 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.30	34.88	22.55	4.66	0.62
08	27.44	34.83	22.47	4.71	0.51
42	27.44	34.83	22.47	4.64	0.48
81	26.55	34.94	22.84	4.39	0.62
158	17.40	34.72	25.22	3.29	1.17
233	11.54	34.67	26.44	1.15	2.39
309	09.90	34.67	26.73	0.59	2.70
466	08.36	34.61	26.93	0.95	2.90
628	07.12	34.54	27.06	0.78	3.17
796	05.70	34.54	27.25	1.03	3.28
973	04.48	34.54	27.39	1.45	3.28
1258 1/		34.61			

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.30	34.88	22.55	0.000	1.767
10	27.44	34.83	22.47	0.053	1.714
20	27.44	34.83	22.47	0.107	1.660
30	27.44	34.83	22.47	0.161	1.606
50	27.44	34.83	22.47	0.269	1.498
75	26.72	34.92	22.77	0.401	1.366
100	25.50	35.06	23.25	0.523	1.244
150	19.75	34.80	24.69	0.723	1.044
200	13.05	34.65	26.13	0.854	0.913
250	11.25	34.68	26.50	0.943	0.824
300	10.07	34.68	26.71	1.018	0.749
400	08.89	34.64	26.87	1.151	0.616
500	08.07	34.59	26.96	1.274	0.493
600	07.32	34.55	27.04	1.390	0.377
700	06.50	34.53	27.14	1.493	0.269
800	05.65	34.54	27.25	1.596	0.171
1000	04.33	34.54	27.41	1.767	0.000

1/ Bottle probably pretripped.

STATION 40

M/V Hugh M. Smith: Cruise 5, 07°00'N, 157°57'W August 1, 1950. Messenger time: 1927 GCT. Weather: scattered clouds, cumulus. Wind: 100°, 17 kt. Sea: 1-3 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.40	34.92	22.55	4.65	0.52
09	27.49	34.90	22.51	4.63	0.46
42	27.50	34.90	22.50	4.66	0.41
84	27.46	34.94	22.55	4.63	0.48
164	14.17	34.61	25.87	1.97	1.70
242	10.53	34.72	26.66	0.63	2.34
320	09.55	34.69	26.80	0.72	2.57
479	08.18	34.61	26.96	0.95	2.74
640	06.69	34.54	27.12	0.50	3.13
802	05.34	34.52	27.28	0.78	3.06
971	04.64	34.54	27.37	1.35	3.09
1245	03.64	34.56	27.49	1.60	3.17

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.40	34.92	22.55	0.000	1.711
10	27.49	34.90	22.51	0.053	1.658
20	27.49	34.90	22.51	0.107	1.604
30	27.49	34.90	22.51	0.160	1.551
50	27.50	34.90	22.50	0.268	1.443
75	27.49	34.91	22.51	0.402	1.309
100	27.38	34.94	22.57	0.536	1.175
150	15.65	34.63	25.56	0.731	0.980
200	11.40	34.67	26.46	0.833	0.878
250	10.45	34.73	26.68	0.909	0.802
300	09.79	34.71	26.78	0.978	0.733
400	08.88	34.65	26.38	1.108	0.603
500	07.98	34.60	26.98	1.229	0.482
600	07.05	34.55	27.08	1.342	0.369
700	06.11	34.52	27.18	1.446	0.265
800	05.35	34.52	27.28	1.540	0.171
1000	04.55	34.54	27.38	1.711	0.000

STATION 41

M/V Hugh M. Smith: Cruise 5, 08°00'N, 157°49'W, August 2, 1950. Messenger time: 0250 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 120°, 13 kt. Sea: 1-3 ft. Wire angle: 27°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/1)	O_2 (ml/1)	PO_4-P (µg at/1)
00	27.70	34.43	22.09	4.66	0.43
09	27.78	34.34	22.00	4.58	0.37
44	27.62	34.45	22.13	4.62	0.37
87	22.18	34.79	24.03	4.14	0.68
172	11.39	34.61	26.42	0.69	2.48
258	09.98	34.69	26.73	0.53	2.73
343	09.28	34.69	26.85	0.58	2.82
518	07.53	34.58	27.03	0.54	3.18
695	06.02	34.52	27.20	0.84	3.28
871	05.01	34.56	27.35	0.85	3.40
1051	04.26	1/		1.30	3.26
1327	03.42	34.56	27.51	1.43	3.23

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/1)	Δ D (dyn. m)	Δ D1000-ΔD (dyn. m)
00	27.70	34.43	22.09	0.000	1.605
10	27.77	34.35	22.00	0.058	1.547
20	27.73	34.36	22.02	0.116	1.489
30	27.68	34.37	22.05	0.174	1.431
50	27.58	34.51	22.18	0.289	1.316
75	26.05	34.93	22.99	0.421	1.184
100	19.45	34.64	24.65	0.524	1.081
150	12.75	34.49	26.07	0.658	0.947
200	10.73	34.66	26.58	0.745	0.860
250	10.04	34.68	26.71	0.818	0.787
300	09.63	34.69	26.79	0.886	0.719
400	08.68	34.65	26.92	1.013	0.592
500	07.68	34.58	27.01	1.131	0.474
600	06.83	34.54	27.10	1.241	0.364
700	06.01	34.52	27.19	1.343	0.262
800	05.40	34.54	27.29	1.437	0.168
1000	04.52	34.56	27.40	1.605	0.000

1/ Sample bottle broken.

STATION 42

M/V Hugh M. Smith: Cruise 5, 09°00'N, 157°55'W, August 2, 1950. Messenger time: 1051 GCT. Weather: showers of rain, no observation. Wind: 130°, 12 kt. Sea: 1-3 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.00	34.31	22.22	4.67	0.41
09	27.15	34.23	22.11	4.65	0.38
49	26.88	34.36	22.30	4.72	0.37
97	14.22	34.33	25.64	3.03	1.16
194	10.29	34.63	26.63	0.44	2.39
290	09.45	34.61	26.76	0.47	2.44
385	08.38	34.56	26.89	0.66	2.64
574	06.58	34.51	27.11	0.56	2.87
765	05.40	34.52	27.27	0.73	2.99
955	04.42	34.52	27.33	1.01	2.87
1147	03.88	34.54	27.45	1.29	2.94
1440	03.22	34.52	27.50	1.26	2.92

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.00	34.31	22.22	0.000	1.503
10	27.15	34.23	22.11	0.057	1.446
20	27.10	34.25	22.14	0.114	1.389
30	27.02	34.27	22.18	0.171	1.332
50	26.83	34.36	22.31	0.283	1.220
75	22.50	34.68	23.35	0.403	1.100
100	13.85	34.32	25.71	0.483	1.020
150	10.98	34.53	26.43	0.582	0.921
200	10.19	34.63	26.65	0.659	0.844
250	09.78	34.62	26.71	0.730	0.773
300	09.33	34.61	26.78	0.798	0.705
400	08.22	34.56	26.92	0.926	0.577
500	07.19	34.53	27.04	1.042	0.461
600	06.38	34.52	27.15	1.148	0.355
700	05.75	34.52	27.23	1.246	0.257
800	05.20	34.52	27.29	1.338	0.165
1000	04.20	34.53	27.41	1.503	0.000

STATION 43

M/V *Hugh M. Smith*: Cruise 5, 10°00'N, 157°53'W, August 2, 1950. Messenger time: 1815 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 070°, 7 kt. Sea: 1-3 ft. Wire angle: 27°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.90	34.13	22.12	4.96	0.43
09	27.03	34.13	22.08	4.58	0.39
44	26.48	34.54	22.56	4.71	0.40
87	23.51	34.58	23.49	4.75	0.48
173	11.34	34.49	26.33	0.78	2.57
258	10.08	34.63	26.67		
343	09.10	34.63	26.83	0.63	2.83
517	07.46	34.54	27.01	0.65	3.11
694	05.86	34.49	27.19	0.79	3.28
872	04.82	34.52	27.34	1.11	3.34
1053	04.11	34.54	27.43	1.26	3.33
1331	03.26	34.58	27.55	1.70	3.45

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.90	34.13	22.12	0.000	1.616
10	27.03	34.13	22.08	0.057	1.559
20	27.03	34.13	22.08	0.115	1.501
30	27.00	34.14	22.09	0.173	1.443
50	26.45	34.55	22.57	0.283	1.333
75	25.71	34.58	22.83	0.413	1.203
100	20.25	34.62	24.43	0.521	1.095
150	12.22	34.36	26.07	0.659	0.957
200	10.84	34.57	26.49	0.748	0.868
250	10.15	34.63	26.66	0.825	0.791
300	09.58	34.63	26.75	0.895	0.721
400	08.55	34.60	26.90	1.025	0.591
500	07.61	34.55	27.00	1.144	0.472
600	06.68	34.51	27.10	1.255	0.361
700	05.81	34.50	27.20	1.357	0.259
800	05.20	34.51	27.29	1.449	0.167
1000	04.34	34.54	27.41	1.616	0.000

STATION 44

M/V Hugh M. Smith: Cruise 5, 11°00'N, 157°55'W, August 3, 1950. Messenger time: 0215 GCT. Weather: broken clouds, cumulus. Wind: 060°, 12 kt. Sea: 1-3 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.10	34.70	22.48	4.69	0.36
09	27.20	34.60	22.37	4.70	0.32
38	26.58	34.70	22.65	4.76	0.34
74	25.84	34.67	22.85	4.81	0.36
145	13.54	34.29	25.75	2.26	1.64
212	10.52	34.54	26.52	0.76	2.33
279	09.90	34.67	26.73	0.35	2.46
412	08.61	34.60	26.88	0.57	2.51
546	07.11	34.49	27.02	0.26	2.92
680	05.90	34.45	27.15	0.52	3.08
819	05.07	34.52	27.31	0.51	3.08
1066	04.02	34.54	27.44	0.97	3.04

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.10	34.70	22.48	0.000	1.625
10	27.17	34.60	22.38	0.054	1.571
20	26.88	34.67	22.53	0.108	1.517
30	26.69	34.70	22.61	0.161	1.464
50	26.42	34.70	22.70	0.266	1.359
75	25.83	34.68	22.87	0.393	1.232
100	21.32	34.82	24.29	0.502	1.123
150	13.05	34.28	25.84	0.649	0.976
200	10.89	34.45	26.39	0.747	0.878
250	10.08	34.64	26.68	0.825	0.800
300	09.72	34.66	26.75	0.894	0.731
400	08.73	34.60	26.87	1.026	0.599
500	07.68	34.53	26.97	1.148	0.477
600	06.60	34.47	27.08	1.261	0.364
700	05.76	34.46	27.18	1.365	0.260
800	05.14	34.51	27.29	1.458	0.167
1000	04.30	34.53	27.40	1.625	0.000

STATION 45

M/V Hugh M. Smith: Cruise 5, 11°59'N, 158°04'W, August 3, 1950. Messenger time: 1016 GCT. Weather: scattered clouds, no observation. Wind: 050°, 11 kt. Sea: 1-3 ft. Wire angle: 25°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	34.67	22.71	4.79	0.46
09	26.48	34.63	22.63	4.72	0.41
44	26.22	34.69	22.75	4.70	0.38
88	22.50	34.87	24.00	5.14	0.40
175	12.20	34.47	26.16	1.29	2.31
260	10.72	34.67	26.59	0.44	2.70
345	09.97	34.69	26.74	0.14	2.82
513	08.20	34.58	26.93	0.24	3.08
683	06.48	34.54	27.15	0.37	3.38
854	05.14	34.52	27.30	0.52	3.48
1028	04.38	34.52	27.39	0.91	3.42
1302	03.51	34.56	27.51	1.29	3.32

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	34.67	22.71	0.000	1.666
10	26.48	34.63	22.63	0.052	1.614
20	26.47	34.63	22.63	0.104	1.562
30	26.35	34.68	22.70	0.156	1.510
50	26.22	34.69	22.75	0.259	1.407
75	25.93	34.71	22.36	0.386	1.280
100	20.08	34.81	24.62	0.492	1.174
150	15.25	34.43	25.50	0.639	1.027
200	11.85	34.53	26.27	0.748	0.918
250	10.88	34.65	26.54	0.832	0.834
300	10.35	34.69	26.67	0.907	0.759
400	09.43	34.66	26.80	1.046	0.620
500	08.32	34.59	26.92	1.174	0.492
600	07.26	34.56	27.06	1.291	0.375
700	06.30	34.54	27.17	1.397	0.269
800	05.46	34.53	27.27	1.493	0.173
1000	04.59	34.52	27.36	1.666	0.000

STATION 46

M/V Hugh M. Smith: Cruise 5, 13°00'N, 157°58'W, August 3, 1950. Messenger time: 1832 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 010°, 8 kt. Sea: 1-3 ft. Wire angle: 03°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.20	34.61	22.70	4.76	0.31
10	26.32	34.56	22.62	4.77	0.33
50	26.24	34.61	22.69	4.78	0.32
99	24.46	34.76	23.34	5.04	0.27
193	12.06	34.54	26.24	0.49	2.41
295	10.54	34.67	26.62	0.26	2.50
393	09.55	34.63	26.76	0.29	2.62
586	07.36	34.51	27.00	0.35	2.89
780	05.69	34.47	27.20	0.47	2.88
974	04.72	34.49	27.32	0.76	2.95
1168	03.99	34.51	27.42	1.11	3.00
1461	03.25	34.54	27.51	1.48	2.92

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.20	34.61	22.70	0.000	1.747
10	26.32	34.56	22.62	0.052	1.695
20	26.30	34.58	22.64	0.104	1.643
30	26.29	34.58	22.65	0.157	1.590
50	26.24	34.61	22.69	0.261	1.486
75	26.18	34.63	22.72	0.390	1.357
100	24.15	34.79	23.46	0.511	1.236
150	15.75	34.48	25.42	0.638	1.059
200	12.00	34.55	26.26	0.799	0.948
250	11.13	34.65	26.50	0.884	0.863
300	10.50	34.67	26.63	0.961	0.786
400	09.48	34.62	26.76	1.104	0.643
500	08.39	34.56	26.89	1.236	0.511
600	07.20	34.50	27.02	1.357	0.390
700	06.20	34.47	27.13	1.466	0.281
800	05.55	34.48	27.22	1.566	0.181
1000	04.63	34.49	27.33	1.747	0.000

STATION 47

M/V Hugh M. Smith: Cruise 5, 14°00'N, 157°54'W, August 4, 1950. Messenger time: 0311 GCT. Weather: broken clouds, cumulus, altostratus and cirrostratus. Wind: 080°, 15 kt. Sea: < 1 ft. Wire angle: 08°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	34.60	22.57	4.78	0.42
10	26.72	34.56	22.50	4.74	0.38
49	26.38	34.56	22.61	4.80	0.39
98	24.48	34.67	23.27	5.02	0.36
195	12.76	34.25	25.88	2.98	1.62
292	09.95	34.52	26.60	0.50	2.78
387	08.98	34.58	26.81	0.48	2.63
578	07.36	34.52	27.01	0.58	3.08
770	05.88	34.47	27.17	0.59	3.26
962	04.98	34.49	27.30	0.67	3.40
1155	04.21	34.49	27.38	1.21	3.18
1446	03.24	34.54	27.52	1.56	3.15

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.60	34.60	22.57	0.000	1.783
10	26.72	34.56	22.50	0.053	1.730
20	26.63	34.56	22.53	0.107	1.676
30	26.51	34.56	22.56	0.160	1.623
50	26.38	34.56	22.60	0.266	1.517
75	26.29	34.56	22.63	0.397	1.386
100	24.15	34.71	23.40	0.520	1.263
150	18.35	34.72	24.99	0.709	1.074
200	12.25	34.27	25.99	0.836	0.947
250	10.50	34.44	26.45	0.929	0.854
300	09.87	34.54	26.63	1.007	0.776
400	08.81	34.58	26.84	1.145	0.638
500	07.98	34.55	26.94	1.271	0.512
600	07.16	34.51	27.03	1.388	0.395
700	06.32	34.48	27.12	1.497	0.286
800	05.69	34.48	27.20	1.598	0.185
1000	04.80	34.49	27.32	1.783	0.000

STATION 48

M/V Hugh M. Smith: Cruise 5, 14°58'N, 157°55'W, August 4, 1950. Messenger time: first cast, 1115 GCT: second cast, 1229 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 20 kt. Sea: 3-5 ft. Wire angle: first cast, 08°; second cast, 07°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.69	22.79	4.73	0.36
10	26.33	34.67	22.70	4.76	0.33
49	26.32	34.65	22.67	4.81	0.32
97	23.08	34.99	23.83	5.22	0.27
192	13.44	34.33	25.80	3.22	1.19
287	10.23	34.54	26.55	0.79	2.46
382	09.20	34.56	26.76	0.46	2.43
574	07.18	34.51	27.03	0.62	2.73
766	05.62	34.49	27.22	0.73	2.92
960	04.72	34.51	27.34	0.84	3.12
1156	03.99	34.54	27.45	1.27	2.95
1450	03.26	34.60	27.55	1.58	3.06
1942	02.31	34.61	27.65	2.04	2.67
1942					2.89
2436	01.91	34.65	27.72	2.62	2.57
2934	01.75	34.67	27.73	2.76	2.43
3430	01.51	34.67	27.76	[illegible]	2.44

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.10	34.69	22.79	0.000	1.748
10	26.33	34.67	22.70	0.051	1.697
20	26.33	34.65	22.70	0.103	1.645
30	26.33	34.65	22.69	0.155	1.593
50	26.31	34.65	22.68	0.259	1.489
75	26.20	34.65	22.71	0.389	1.359
100	22.90	35.01	23.99	0.503	1.245
150	18.81	34.86	24.98	0.679	1.069
200	12.58	34.34	25.98	0.808	0.940
250	10.51	34.53	26.52	0.900	0.848
300	10.19	34.54	26.58	0.979	0.769
400	08.98	34.56	26.80	1.123	0.625
500	07.90	34.54	26.95	1.250	0.498
600	06.92	34.51	27.07	1.366	0.382
700	06.06	34.49	27.16	1.472	0.276
800	05.40	34.49	27.25	1.569	0.179
1000	04.62	34.51	27.55	1.748	0.000

STATION 49

M/V Hugh M. Smith: Cruise 5, 17°00'N, 158°08'W, August 5, 1950. Messenger time: 0412 GCT. Weather: broken clouds, cumulus, altostratus and cirrus. Wind: 080°, 17 kt. Sea: 3-5 ft. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	34.81	23.04	4.82	0.46
08	25.78	34.79	22.96	4.85	0.26
44	25.67	34.79	22.99	4.90	0.26
87	24.76	34.78	23.27	5.00	0.29
171	20.74	35.14	24.69	4.75	0.35
253	14.02	34.40	25.74	4.07	0.97
332	09.70	34.18	26.38	2.99	1.94
493	06.79	34.31	26.93	0.97	2.87
656	05.54	34.36	27.12	0.84	3.08
823	04.82	34.42	27.26	0.93	3.13
999	04.20	34.49	27.38	1.16	3.16
1279	03.40	34.52	27.48	1.40	3.11

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.60	34.81	23.04	0.000	1.867
10	25.78	34.79	22.96	0.049	1.818
20	25.76	34.79	22.97	0.098	1.769
30	25.73	34.79	22.98	0.147	1.720
50	25.66	34.79	23.00	0.245	1.622
75	25.01	34.78	23.19	0.365	1.502
100	24.25	34.80	23.44	0.480	1.387
150	21.66	35.18	24.47	0.681	1.186
200	18.82	34.96	25.06	0.844	1.023
250	14.20	34.42	25.72	0.977	0.890
300	11.03	34.18	26.15	1.084	0.783
400	08.08	34.30	26.73	1.251	0.616
500	06.70	34.32	26.95	1.380	0.487
600	05.95	34.34	27.06	1.494	0.373
700	05.31	34.37	27.16	1.598	0.269
800	04.89	34.41	27.24	1.694	0.173
1000	04.19	34.49	27.38	1.867	0.000

STATION 50

M/V Hugh M. Smith: Cruise 5, 19°02'N, 157°59'W, August 5, 1950. Messenger time: 2035 GCT. Weather: broken clouds, cumulus, altocumulus and altostratus. Wind: 050°, 14 kt. Sea: 1-3 ft. Wire angle: 03°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.90	34.72	22.87	4.88	0.31
10	26.12	34.70	22.79	4.85	0.26
50	25.30	34.72	23.06	5.04	0.23
99	22.87	35.12	24.08	4.97	0.24
196	18.96	34.96	25.02	4.54	0.40
292	11.60	34.18	26.05	4.09	1.17
388	08.02	34.09	26.58	2.56	2.11
530	05.70	34.25	27.02	0.84	2.61
774	04.86	34.38	27.22	0.92	2.57
967	04.22	34.47	27.36	1.10	2.77
1161	03.66	34.49	27.44	1.25	2.66
1455	02.85	34.49	27.51	1.53	2.75

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.90	34.72	22.87	0.000	1.858
10	26.12	34.70	22.79	0.050	1.808
20	26.05	34.70	22.81	0.101	1.757
30	26.01	34.70	22.83	0.152	1.706
50	25.30	34.72	23.06	0.251	1.607
75	23.70	34.97	23.73	0.364	1.494
100	22.82	35.12	24.10	0.464	1.394
150	20.56	35.12	24.72	0.643	1.215
200	18.81	34.94	25.04	0.800	1.058
250	16.25	34.64	25.43	0.941	0.917
300	11.22	34.16	26.10	1.056	0.802
400	07.82	34.09	26.61	1.231	0.627
500	06.32	34.17	26.88	1.369	0.489
600	05.59	34.27	27.05	1.486	0.372
700	05.13	34.33	27.15	1.591	0.267
800	04.78	34.40	27.25	1.687	0.171
1000	04.10	34.48	27.38	1.858	0.000

STATION 51

M/V *Hugh M. Smith*: Cruise 5, 20°53'N, 158°02'W, August 6, 1950. Messenger time: 0930 GCT. Weather: scattered clouds, no observation. Wind: 060°, 19 kt. Sea: 3-5 ft. Wire angle: 25°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.10	34.83	23.20	4.95	0.32
09	25.23	34.78	23.13	4.92	0.31
46	25.24	34.78	23.12	4.94	0.26
91	23.46	34.96	23.79	5.19	0.28
181	19.20	34.88	24.90	4.62	0.44
270	14.12	34.38	25.70	4.13	0.94
359	09.52	34.11	26.36	3.50	1.78
538	06.34	34.16	26.87	1.20	2.82
717	05.07	34.36	27.18	0.97	3.11
901	04.38	34.45	27.33	1.14	3.13
1088	03.80	34.51	27.44	1.27	3.11
1374	03.13	34.54	27.53	1.49	3.04

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	25.10	34.83	23.20	0.000	1.887
10	25.23	34.78	23.13	0.047	1.840
20	25.23	34.78	23.13	0.095	1.792
30	25.24	34.78	23.12	0.142	1.745
50	25.24	34.78	23.12	0.238	1.649
75	24.00	34.90	23.59	0.352	1.535
100	23.11	34.98	23.91	0.457	1.430
150	20.78	34.98	24.56	0.644	1.243
200	18.02	34.78	25.12	0.803	1.084
250	15.45	34.51	25.51	0.940	0.947
300	12.32	34.24	25.96	1.057	0.830
400	08.45	34.10	26.52	1.243	0.644
500	06.78	34.14	26.79	1.389	0.498
600	05.81	34.23	26.99	1.514	0.373
700	05.15	34.34	27.16	1.621	0.266
800	04.65	34.41	27.27	1.716	0.171
1000	04.20	34.47	27.37	1.887	0.000

STATION 1

M/V *Hugh M. Smith*: Cruise 8, 20°48'N, 157°30'W, January 15, 1951. Messenger time: 0522 GCT. Weather: overcast (with breaks), no observation. Wind: 070°, 35 kt. Sea: 12 to 20 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	24.50	34.88	23.42	4.94	
10	24.51	34.88	23.42	4.83	
26	24.52	34.88	23.42	4.85	
51	24.52	34.88	23.42	4.98	
100	24.42	34.96	23.51	4.92	
200	17.41	34.74	25.24	4.22	
302	11.93	34.22	26.02	4.05	
397	08.76	34.13	26.50	3.00	
498		34.92			
595	05.98	34.29	27.02	1.54	
797	04.74	34.43	27.28	0.93	
999	04.00	34.50	27.41	1.23	
1197	03.61	34.56	27.50	1.39	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.50	34.88	23.42	0.000	1.854
10	24.51	34.88	23.42	0.045	1.809
20	24.51	34.88	23.42	0.090	1.764
30	24.52	34.88	23.42	0.134	1.720
50	24.52	34.88	23.42	0.224	1.630
75	24.48	34.92	23.46	0.336	1.518
100	24.42	34.96	23.51	0.447	1.407
150	21.17	35.22	24.63	0.642	1.212
200	17.41	34.74	25.24	0.797	1.057
250	13.87	34.39	25.76	0.925	0.929
300	12.00	34.22	26.00	1.035	0.819
400	08.67	34.13	26.51	1.219	0.635
500	07.00	34.20	26.81	1.365	0.489
600	05.93	34.29	27.02	1.488	0.366
700	05.20	34.37	27.17	1.593	0.261
800	04.70	34.41	27.26	1.687	0.167
1000	03.99	34.50	27.41	1.854	0.000

STATION 2

M/V Hugh M. Smith: Cruise 8, 18°47'N, 158°01'W, January 15-16, 1951. Messenger time: first cast, 2330 GCT; second cast, 0000 GCT. Weather: scattered clouds, no observation. Wind: 090°, 25 kt. Sea: 12 to 20 ft. Wire angle: first cast, 50°: second cast, no observation

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
[3]00				4.85	
19	24.58	34.84	23.37	4.82	
40	24.56	34.83	23.37	4.79	
73	24.49	34.83	23.39	4.83	
143	24.08	35.05	23.68	4.81	
206	20.20	35.15	24.84	4.69	
268	15.00	34.45	25.57	3.97	
333[1]	11.23	34.21	26.14	3.61	
301 [1]/[2] 394	10.85	34.19	26.19	3.83	
437 [1]/[2] 527	08.72	34.35	26.67	1.18	
521 [1]/[2] 662	07.20	34.33	26.89	0.87	
795 [1]	05.56	34.41	27.16	0.78	
795	05.94	34.41	27.12		

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.60	34.84	23.36		
10	24.59	34.84	23.37		
20	24.58	34.84	23.37		
30	24.57	34.83	23.36		
50	24.52	34.83	23.38		
75	24.48	34.84	23.40		
100	24.40	34.88	23.45		
150	24.00	35.07	23.72		
200	21.07	35.23	24.67		
250	17.03	34.70	25.30		

[1] Bottles below 268 m. apparently pretripped.

[2] Double depths result from disagreement between readings of unprotected thermometers at these depths.

[3] First 2 Nansen bottles omitted from cast. Surface oxygen value obtained from a bucket sample.

STATION 4

M/V Hugh M. Smith: Cruise 8, 14°30'N, 158°00'W, January 17, 1951. Messenger time: 1808 GCT. Weather: scattered clouds, cumulus. Wind: 060°, 28 kt. Sea: 12 to 20 ft. Wire angle: 45°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00		34.62		4.85	
11	24.52	34.44	23.09	4.77	
24	24.52	34.43	23.08	4.83	
51	24.52	34.43	23.08	4.77	
99	21.44	35.21	24.55	4.74	
190	14.82	34.43	25.59	3.91	
278	10.62	34.52	26.49	0.71	
369	08.65	34.44	26.75	0.53	
457	07.37	34.42	26.93	0.65	
550	06.48	34.43	27.06	0.66	
742	05.21	34.46	27.23	0.86	
942	04.37	34.50	27.37	1.04	
868 1/	04.78	34.50	27.33	1.06	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	24.50	34.62	23.23	0.000	1.646
10	24.52	34.44	23.08	0.047	1.599
20	24.52	34.43	23.08	0.095	1.551
30	24.52	34.43	23.08	0.143	1.503
50	24.52	34.43	23.08	0.297	1.349
75	22.62	35.22	24.23	0.347	1.299
100	21.40	35.20	24.56	0.436	1.210
150	19.00	34.95	25.00	0.598	1.048
200	13.92	34.38	25.74	0.732	0.914
250	11.09	34.46	26.36	0.834	0.812
300	10.07	34.60	26.65	0.914	0.732
400	08.13	34.42	26.82	1.054	0.592
500	06.90	34.43	27.00	1.177	0.469
600	06.11	34.44	27.12	1.286	0.360
700	05.47	34.46	27.21	1.386	0.260
800	04.89	34.48	27.30	1.478	0.168
1000	(04.20)	(34.50)	27.39	1.646	0.000

1/ Bottom bottle pretripped.

STATION 6

M/V *Hugh M. Smith*: Cruise 8, 13°00'N, 158°00'W, January 18, 1951. Messenger time: 0740 GCT. Weather: broken clouds, no observation. Wind: 090°, 23 kt. Sea: 12-20 ft. Wire angle: 22°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.40	34.21	22.64	4.73	
14	25.39	34.23	22.66	4.77	
32	25.40	34.22	22.65	4.79	
69	25.36	34.27	22.70	4.74	
136	13.85	34.39	25.77	2.79	
266	09.86	34.62	26.70	0.41	
402	08.67	34.57	26.85	0.39	
534	07.51	34.52	26.99	0.45	
674	06.28	34.47	27.12	0.38	
814	05.36	34.50	27.26	0.51	
1101	04.25	34.52	27.40	0.78	
1381	03.45	34.56	27.51	1.37	
1680	02.81	34.55	27.56	1.72	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.40	34.21	22.64	0.000	1.604
10	25.38	34.22	22.66	0.052	1.552
20	25.39	34.23	22.66	0.104	1.500
30	25.40	34.22	22.65	0.156	1.448
50	25.40	34.24	22.67	0.261	1.343
75	24.30	34.80	23.42	0.382	1.222
100	18.30	34.53	24.86	0.478	1.126
150	12.70	34.40	26.01	0.608	0.996
200	10.85	34.55	26.47	0.700	0.904
250	10.06	34.63	26.67	0.776	0.828
300	09.55	34.60	26.74	0.847	0.757
400	08.70	34.57	26.85	0.981	0.623
500	07.86	34.54	26.95	1.106	0.498
600	06.91	34.49	27.05	1.222	0.382
700	06.12	34.48	27.15	1.329	0.275
800	05.46	34.50	27.25	1.427	0.177
1000	04.53	34.52	27.37	1.604	0.000

STATION 7

M/V *Hugh M. Smith*: Cruise 8, 11°59'N, 157°50'W, January 18, 1951. Messenger time: 1726 GCT. Weather: broken clouds, cumulus and stratocumulus. Wind: 090°, 23 kt. Sea: 12-20 ft. Wire angle: 09°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00		34.23		4.73	
10	25.60	34.23	22.60	4.74	
30	25.61	34.21	22.58	4.72	
45	25.62	34.22	22.58	4.71	
152	13.75	34.34	25.75	3.04	
270	09.92	34.62	26.69	0.44	
386	08.95	34.57	26.81	0.71	
498	07.99	34.53	26.93	0.54	
611		34.21			
723	06.10	34.51	27.18	0.34	
954	04.72	34.50	27.33	0.73	
1173	03.87	34.55	27.46	1.31	
1385	03.28	34.53	27.50	1.51	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.60	34.23	22.60	0.000	1.660
10	25.60	34.23	22.60	0.053	1.607
20	25.61	34.22	22.59	0.105	1.555
30	25.61	34.21	22.58	0.158	1.502
50	25.62	34.22	22.58	0.264	1.396
75	25.50	34.26	22.65	0.395	1.265
100	21.90	35.23	24.44	0.505	1.155
150	14.00	34.35	25.70	0.652	1.008
200	11.00	34.55	26.44	0.751	0.909
250	10.10	34.62	26.66	0.829	0.831
300	09.68	34.60	26.71	0.900	0.760
400	08.82	34.57	26.83	1.035	0.625
500	07.97	34.53	26.93	1.161	0.499
600	07.12	34.52	27.05	1.278	0.382
700	06.30	34.51	27.15	1.385	0.275
800	05.55	34.50	27.24	1.484	0.176
1000	04.53	34.52	27.37	1.660	0.000

STATION 8

M/V Hugh M. Smith: Cruise 8, 11°00'N, 157°53'W, January 19, 1951. Messenger time: 0150 GCT. Weather: broken clouds, cumulus. Wind: 090°, 20 kt. Sea: 3-5 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00		34.34		4.77	
10	25.88	34.33	22.59	4.73	
27	25.88	34.3I	22.57	4.72	
55	25.84	34.31	22.58	4.72	
108	17.58	34.69	25.16	4.24	
214	10.75	34.62	26.54	0.34	
318	09.70	34.68	26.77	0.30	
419	08.78	34.59	26.85	0.36	
526	07.59	34.53	26.99	0.55	
629	06.57	34.45	27.06	0.48	
843	05.12	34.54	27.32	0.45	
1049	04.23	34.51	27.39	1.25	
1261	03.60	34.53	27.47	1.49	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.80	34.34	22.62	0.000	1.571
10	25.88	34.33	22.59	0.053	1.518
20	25.88	34.32	22.58	0.105	1.466
30	25.88	34.31	22.57	0.158	1.413
50	25.86	34.31	22.58	0.264	1.307
75	23.20	35.08	23.96	0.380	1.191
100	18.80	34.81	24.95	0.468	1.103
150	12.46	34.40	26.05	0.595	0.976
200	10.87	34.61	26.51	0.684	0.887
250	10.35	34.70	26.68	0.759	0.812
300	09.88	34.70	26.76	0.829	0.742
400	08.93	34.61	26.84	0.961	0.610
500	07.88	34.55	26.96	1.086	0.485
600	06.83	34.46	27.04	1.201	0.370
700	06.03	34.48	27.16	1.308	0.263
800	05.38	34.54	27.29	1.403	0.168
1000	04.40	34.53	27.39	1.571	0.000

STATION 9

M/V Hugh M. Smith: Cruise 8, 10°06'N, 157°56'W, January 19, 1951. Messenger time: 1[illegible]2 GCT. Weather: overcast (with breaks), cumulus. Wind: 080°, 22 kt. Sea: 5-8 ft. Wire angle: 13°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00		34.33		4.68	
10	26.08	34.24	22.46	4.67	
23	26.10	34.28	22.48	4.69	
53	26.09	34.27	22.48	4.68	
106	17.68	34.61	25.07	4.26	
210	10.76			0.60	
311	09.50	34.63	26.77	0.53	
419	08.45	34.59	26.90	0.65	
522	07.49	34.50	26.98	0.81	
627	06.58	34.55	27.14	0.80	
830	05.22	34.48	27.26	1.00	
1027	04.36	34.52	27.40	1.37	
1239	03.71	34.52	27.46	1.51	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	26.10	34.33	22.52	0.000	1.575
10	26.08	34.24	22.46	0.054	1.521
20	26.10	34.27	22.47	0.108	1.467
30	26.10	34.28	22.48	0.161	1.414
50	26.09	34.27	22.48	0.269	1.306
75	22.50	34.83	23.97	0.386	1.189
100	18.12	34.85	24.96	0.474	1.101
150	12.48	34.55	26.17	0.598	0.977
200	11.00	34.63	26.51	0.685	0.890
250	10.12	34.65	26.63	0.761	0.814
300	09.63	34.64	26.75	0.831	0.744
400	08.66	34.60	26.88	0.962	0.613
500	07.71	34.52	26.96	1.086	0.489
600	06.82	34.54	27.10	1.199	0.376
700	06.06	34.52	27.19	1.302	0.273
800	05.42	34.48	27.24	1.399	0.176
1000	04.45	34.52	27.38	1.575	0.000

STATION 10

M/V Hugh M. Smith: Cruise 8, 09°00'N, 157°58'W, January 19, 1951. Messenger time: first cast, 1930 GCT; second cast, 2015 GCT. Weather: continuous moderate rain, nimbostratus. Wind: 090°, 22 kt. Sea: 12-20 ft. Wire angle: first cast, 10°; second cast, 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
07	26.45	34.24	22.34	4.70	
13	26.45	34.24	22.34	4.72	
22	26.46	34.25	22.35	4.73	
53	26.47	34.23	22.33	4.70	
107	15.57	34.59	25.55	3.60	
217	10.48	34.69	26.64	0.39	
325	09.48	34.67	26.80	0.63	
435	08.49	34.59	26.90	0.56	
540	07.26	34.53	27.03	0.67	
646	06.32	34.51	27.15	0.73	
897	04.94	34.58	27.37	0.91	
1103	04.06	34.52	27.42	1.26	
1305	03.52	34.61	27.54	1.50	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	(26.50)	(34.24)	22.33	0.000	1.547
10	26.45	34.24	22.34	0.055	1.492
20	26.45	34.25	22.35	0.110	1.437
30	26.46	34.24	22.34	0.165	1.382
50	26.47	34.23	22.33	0.276	1.271
75	23.12	34.77	23.75	0.397	1.150
100	17.72	34.69	25.12	0.486	1.061
150	11.55	34.64	26.41	0.599	0.948
200	10.68	34.68	26.60	0.678	0.869
250	10.28	34.69	26.68	0.751	0.796
300	09.73	34.69	26.78	0.820	0.727
400	08.80	34.62	26.87	0.950	0.597
500	07.73	34.55	26.98	1.072	0.475
600	06.71	34.51	27.09	1.184	0.363
700	05.93	34.52	27.20	1.286	0.261
800	05.39	34.55	27.29	1.378	0.169
1000	04.48	34.54	27.39	1.547	0.000

STATION 11

M/V *Hugh M. Smith*: Cruise 8, 08°04'N, 157°58'W, January 20, 1951. Messenger time: 0540 GCT. Weather: broken clouds, no observation. Wind: 090°, 23 kt. Sea: 12-20 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	34.50	22.46	4.65	
10	26.72	34.50	22.45	4.70	
25	26.72	34.50	22.45	4.77	
55	26.76	34.50	22.44	4.66	
110	18.27	34.74	25.02	3.12	
215	10.64	34.66	26.60	0.86	
320	09.44	34.67	26.81	0.98	
429	08.66	34.61	26.89	1.20	
533	07.63	34.58	27.02	0.78	
638	06.59	34.54	27.13	1.00	
843	05.40	34.53	27.28	0.79	
1050	04.42	34.52	27.38	1.51	
1256	03.68	34.57	27.50	1.48	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	26.70	34.50	22.46	0.000	1.581
10	26.72	34.50	22.45	0.054	1.527
20	26.72	34.50	22.45	0.108	1.473
30	26.72	34.50	22.45	0.162	1.419
50	26.75	34.50	22.44	0.270	1.311
75	23.40	34.95	23.80	0.390	1.191
100	18.79	34.77	24.92	0.480	1.101
150	13.45	34.53	25.96	0.610	0.971
200	11.00	34.63	26.51	0.702	0.879
250	10.19	34.69	26.70	0.776	0.805
300	09.62	34.68	26.79	0.845	0.736
400	08.88	34.62	26.86	0.975	0.606
500	08.00	34.59	26.97	1.098	0.483
600	06.94	34.55	27.09	1.211	0.370
700	06.18	34.61	27.24	1.311	0.270
800	05.64	34.53	27.25	1.404	0.177
1000	04.67	34.52	27.35	1.581	0.000

STATION 12

M/V Hugh M. Smith: Cruise 8, 07°08'N, 157°58'W, January 20, 1951. Messenger time: 1413 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 20 kt. Sea: 5-8 ft. Wire angle: 12°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	34.39	22.38	4.63	
10	26.71	34.37	22.36	4.64	
26	26.72	34.39	22.37	4.64	
55	26.74	34.48	22.43	4.63	
108	18.52	34.67	24.91	3.52	
217	10.42	34.70	26.66	0.82	
323	09.15	34.64	26.83	1.07	
433	08.48	34.59	26.90	1.05	
538	07.74	34.56	26.99	0.88	
642	06.71	34.52	27.10	0.87	
851	05.31	34.52	27.28	1.25	
1065	04.32	34.53	27.40	1.43	
1267	03.78	34.53	27.46	1.59	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.70	34.39	22.38	0.000	1.646
10	26.71	34.37	22.36	0.055	1.591
20	26.72	34.38	22.36	0.110	1.536
30	26.72	34.40	22.38	0.165	1.481
50	26.73	34.47	22.43	0.274	1.372
75	25.40	34.94	23.19	0.401	1.245
100	24.00	35.06	23.71	0.513	1.133
150	13.31	34.50	25.96	0.671	0.975
200	10.83	34.68	26.58	0.761	0.885
250	10.02	34.69	26.73	0.834	0.812
300	09.40	34.66	26.81	0.901	0.745
400	08.68	34.61	26.88	1.029	0.617
500	08.07	34.57	26.95	1.152	0.494
600	07.15	34.53	27.05	1.268	0.378
700	06.28	34.52	27.16	1.375	0.271
800	05.57	34.52	27.25	1.472	0.174
1000	04.56	34.53	27.37	1.646	0.000

STATION 13

M/V *Hugh M. Smith*: Cruise 8, 05°59'N, 158°00'W, January 21, 1951. Messenger time: 0020 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 100°, 18 kt. Sea: 5-8 ft. Wire angle: 0°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.60	35.11	22.95	4.71	
09	26.60	35.12	22.96	4.65	
35	26.56	35.11	22.96	4.64	
66	26.54	35.08	22.94	4.65	
121	25.18	35.15	23.42	4.13	
232	10.31	34.72	26.70	0.54	
338	08.92	34.65	26.88	1.53	
460	08.18	34.57	26.93	1.33	
553	07.38	34.60	27.07	0.82	
662	06.31	34.54	27.17	0.53	
887	04.89	34.55	27.35	1.10	
1097	04.12	34.59	27.47	1.44	
1296	03.52	34.61	27.54	1.68	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.60	35.11	22.95	0.000	1.652
10	26.60	35.12	22.96	0.049	1.603
20	26.58	35.12	22.96	0.098	1.554
30	26.57	35.11	22.96	0.148	1.504
50	26.55	35.10	22.96	0.246	1.406
75	26.52	35.09	22.96	0.370	1.282
100	25.87	35.15	23.21	0.490	1.162
150	17.24	34.58	25.15	0.680	0.972
200	11.65	34.64	26.39	0.794	0.858
250	10.09	34.72	26.74	0.870	0.782
300	09.40	34.68	26.82	0.937	0.715
400	08.50	34.59	26.90	1.064	0.588
500	07.86	34.57	26.98	1.185	0.467
600	06.90	34.58	27.12	1.295	0.357
700	06.00	34.54	27.21	1.396	0.256
800	05.30	34.55	27.31	1.487	0.165
1000	04.46	34.57	27.42	1.652	0.000

STATION 14

M/V Hugh M. Smith: Cruise 8, 05°00'N, 158°00'W, January 21, 1951. Messenger time: 0845 GCT. Weather: scattered clouds, no observation. Wind: 130°, 25 kt. Sea: 8-12 ft. Wire angle: 15°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	35.09	22.97	4.64	
10	26.46	35.08	22.97	4.56	
25	26.41	35.12	23.01	4.61	
55	26.20	35.10	23.07	4.58	
112	26.11	35.16	23.14	4.47	
214	11.78	34.63	26.36	1.17	
319	09.20	34.67	26.85	1.63	
426	08.26	34.61	26.95	1.18	
530	07.68	34.59	27.02	0.96	
633	06.66	34.56	27.14	0.80	
836	05.14	34.53	27.31	1.00	
1046	04.24	34.56	27.43	1.40	
1046	04.32	34.56	27.42		
1252	03.52	34.56	27.50	1.78	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.50	35.09	22.97	0.000	1.740
10	26.46	35.08	22.97	0.049	1.691
20	26.44	35.09	22.98	0.098	1.642
30	26.40	35.12	23.02	0.147	1.593
50	26.20	35.10	23.07	0.244	1.496
75	26.18	35.12	23.09	0.364	1.376
100	26.12	35.16	23.14	0.485	1.255
150	24.12	35.10	23.70	0.711	1.029
200	12.77	34.55	26.11	0.866	0.874
250	10.60	34.71	26.64	0.952	0.788
300	09.52	34.69	26.81	1.021	0.719
400	08.47	34.62	26.92	1.147	0.593
500	07.88	34.59	26.99	1.266	0.474
600	06.97	34.57	27.11	1.377	0.363
700	06.13	34.55	27.20	1.479	0.261
800	05.38	34.53	27.28	1.572	0.168
1000	04.44	34.56	27.41	1.740	0.000

STATION 15

M/V Hugh M. Smith: Cruise 8, 03°55'N, 157°54'W, January 21, 1951. Messenger time: 2015 GCT. Weather: scattered clouds, cumulus. Wind: 140°, 22 kt. Sea: 5-8 ft. Wire angle: 42°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	26.22	35.07	23.04	4.61	
09	26.22	35.08	23.04	4.61	
15	26.22	35.12	23.03	4.68	
46	26.16	35.07	23.06	4.60	
83	25.87	35.07	23.15	4.61	
160	22.10	34.94	24.16	3.67	
240	10.46	34.61	26.59	2.30	
321	09.70	34.69	26.78	2.37	
406		34.61		1.07	
488	07.73	34.59	27.01	0.93	
480 1/	07.78	34.59	27.00	0.99	
597 1/	06.68	34.58	27.15	0.93	
708 1/	05.78	34.55	27.25	1.31	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
.00	(26.20)	(35.07)	23.04		
10	26.22	35.08	23.05		
20	26.22	35.11	23.07		
30	26.20	35.10	23.07		
50	26.12	35.07	23.07		
75	25.95	35.07	23.12		
100	25.60	35.10	23.25		
150	25.39	35.11	23.33		
200	12.70	34.55	26.12		
250	10.30	34.64	26.64		
300	09.90	34.68	26.74		
400	08.65	34.61	26.89		
500	07.62	34.59	27.03		
600	06.65	34.58	27.16		
700	05.82	34.56	27.25		

1/ Probable pretrip.

STATION 16

M/V Hugh M. Smith: Cruise 8, 03°02'N, 157°57'W, January 22, 1951. Messenger time: 0640 GCT. Weather: overcast (with breaks), altocumulus. Wind: 110°, 19 kt. Sea: 5-8 ft. Wire angle: 51°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.20	35.08	23.05	4.62	
04	26.26	35.09	23.04	4.64	
26	26.28	35.10	23.04	4.67	
50	26.14	35.08	23.07	4.62	
91	25.60	35.11	23.26	4.67	
170	22.68	34.98	24.03	3.68	
246	10.68	34.69	26.61	2.40	
336	09.90	34.72	26.77	2.09	
419	08.60	34.66	26.93	1.31	
511	07.60	34.60	27.04	1.31	
709	05.80	34.56	27.25	1.65	
923	04.84	34.57	27.38	1.88	
1166	03.94	34.56	27.46	1.84	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.20	35.08	23.05	0.000	1.754
10	26.26	35.09	23.04	0.048	1.706
20	26.28	35.10	23.04	0.097	1.657
30	26.28	35.10	23.04	0.145	1.609
50	26.14	35.08	23.07	0.242	1.512
75	25.85	35.11	23.18	0.361	1.393
100	25.50	35.11	23.29	0.478	1.276
150	25.50	35.11	23.29	0.711	1.043
200	12.33	34.63	26.26	0.872	0.882
250	10.65	34.70	26.62	0.955	0.799
300	10.20	34.72	26.72	1.027	0.727
400	09.90	34.68	26.74	1.167	0.587
500	07.73	34.60	27.02	1.294	0.460
600	06.75	34.57	27.14	1.402	0.352
700	05.87	34.56	27.24	1.500	0.254
800	05.33	34.56	27.31	1.589	0.165
1000	04.50	34.57	27.41	1.754	0.000

STATION 17

M/V Hugh M. Smith: Cruise 8, 02°00'N, 153°01'W, January 22, 1951. Messenger time: first cast, 1623 GCT; second cast, 1730 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 110°, 19 kt. Sea: 5-8 ft. Wire angle: first cast, 46°; second cast, 49°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	35.08	23.24	4.59	
11	25.62	35.08	23.23	4.64	
26	25.64			4.65	
56	25.64	35.09	23.23	4.62	
104	25.51	35.10	23.28	4.62	
194	15.22	34.74	25.74	2.42	
276 1/	10.42	34.90	26.82	1.57	
375	09.62	34.70	26.80	1.48	
466	08.39	34.65	26.96	1.23	
569	07.47	34.56	27.03	1.28	
792	05.34	34.50	27.26	1.68	
1121	04.06	34.55	27.44	2.03	
1397	03.20	34.56	27.54	2.03	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.60	35.08	23.24	0.000	1.774
10	25.62	35.08	23.23	0.047	1.727
20	25.63	35.08	23.23	0.093	1.681
30	25.64	35.09	23.23	0.140	1.634
50	25.64	35.09	23.23	0.233	1.541
75	25.60	35.09	23.25	0.350	1.424
100	25.53	35.10	23.28	0.466	1.308
150	24.95	35.09	23.45	0.695	1.079
200	14.98	34.73	25.79	0.865	0.909
250	10.70	34.74	26.65	0.958	0.816
300	10.22	34.72	26.72	1.030	0.744
400	09.32	34.68	26.84	1.165	0.609
500	08.06	34.62	26.99	1.289	0.485
600	07.18	34.54	27.05	1.403	0.371
700	06.10	34.51	27.17	1.508	0.266
800	05.28	34.50	27.27	1.603	0.171
1000	04.47	34.54	27.39	1.774	0.000

1/ Anomalous values at this depth. Bottle apparently leaked on way up.

STATION 18

M/V Hugh M. Smith: Cruise 8, 00°58'N, 158°07'W, January 23, 1951. Messenger time: 0245 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 12 kt. Sea: 3-5 ft. Wire angle: 50°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.20	35.07	23.35	4.73	
11	25.20	35.08	23.36		
24	24.94	35.05	23.42	4.70	
47	24.90	35.04	23.42	4.65	
90	24.83	35.06	23.46	4.61	
158	21.72				
230	11.94	34.81	26.47	2.71	
310	10.60	34.74	26.66	1.66	
389	09.79	34.65	26.73	1.40	
476	07.94	34.56	26.96	1.18	
645	06.40	34.50	27.13	1.61	
818	05.19	34.50	27.28	2.00	
1052	04.28	34.50	27.38	2.02	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.20	35.07	23.35	0.000	1.748
10	25.20	35.08	23.36	0.045	1.703
20	24.95	35.06	23.42	0.090	1.658
30	24.93	35.05	23.42	0.135	1.613
50	24.90	35.04	23.42	0.225	1.523
75	24.87	35.05	23.44	0.337	1.411
100	24.83	35.06	23.46	0.449	1.299
150	23.82	35.04	23.75	0.666	1.082
200	14.67	34.72	25.85	0.827	0.921
250	11.49	34.79	26.54	0.922	0.826
300	10.73	34.75	26.65	0.998	0.750
400	09.59	34.64	26.76	1.140	0.608
500	07.63	34.55	27.00	1.267	0.481
600	06.70	34.50	27.09	1.378	0.370
700	05.92	34.50	27.19	1.481	0.267
800	05.28	34.50	27.27	1.575	0.173
1000	04.41	34.50	27.37	1.748	0.000

STATION 19

M/V Hugh M. Smith: Cruise 8, 00°01'N, 158°02'W, January 23, 1951. Messenger time: 1132 GCT. Weather: broken clouds, cumulus. Wind: 070°, 12 kt. Sea: 5-8 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.00	35.17	23.49	4.53	
09	25.00				
20	25.01	35.25	23.55	4.53	
41	24.88	35.17	23.53	4.45	
79	24.80	35.15	23.54	4.43	
155	21.80			3.30	
233	12.84	34.94	26.40	3.13	
316	10.76	34.75	26.64	1.88	
396	09.46	34.70	26.83	1.28	
483	08.23	34.65	26.98	1.37	
649	06.08	34.56	27.22	1.74	
815	05.09	34.52	27.31	1.96	
986	04.25	34.59	27.45	1.99	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.00	35.17	23.49	0.000	1.691
10	25.00	35.20	23.51	0.044	1.647
20	25.01	35.25	23.55	0.088	1.603
30	24.96	35.21	23.53	0.131	1.560
50	24.86	35.17	23.53	0.219	1.472
75	24.81	35.15	23.53	0.329	1.362
100	24.66	35.14	23.57	0.438	1.253
150	21.90	35.10	24.34	0.639	1.052
200	17.20	35.05	25.52	0.793	0.898
250	12.35	34.88	26.45	0.898	0.793
300	11.05	34.78	26.61	0.977	0.714
400	09.38	34.70	26.84	1.117	0.574
500	07.98	34.64	27.01	1.239	0.452
600	06.60	34.59	27.17	1.346	0.345
700	05.72	34.54	27.25	1.441	0.250
800	05.13	34.52	27.30	1.531	0.160
1000	(04.20)	(34.59)	27.46	1.691	0.000

STATION 20

M/V Hugh M. Smith: Cruise 8, 00°55'S, 157°54'W, January 23, 1951. Messenger time: 2122 GCT. Weather: scattered clouds, cumulus. Wind: 140°, 13 kt. Sea: 5-8 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.30	35.27	23.47	4.65	
11	25.18				
26	25.16	35.21	23.47	4.62	
52	25.12	35.26	23.52	4.57	
102	25.10	35.25	23.52	4.51	
204	16.85	35.47	25.93	2.79	
302	10.68	34.81	26.70	2.19	
412	09.32	34.70	26.85	1.65	
515	07.70	34.59	27.02	1.36	
628	06.50	34.57	27.17	1.62	
850	04.96	34.54	27.34	2.28	
1083	04.07	34.54	27.44	2.23	
1349	03.30	34.58	27.54	2.14	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.30	35.27	23.47	0.000	1.718
10	25.19	35.25	23.49	0.044	1.674
20	25.17	35.22	23.48	0.088	1.630
30	25.15	35.22	23.48	0.133	1.585
50	25.12	35.26	23.52	0.221	1.497
75	25.11	35.26	23.53	0.331	1.387
100	25.10	35.25	23.52	0.441	1.277
150	24.97	35.26	23.57	0.661	1.057
200	17.12	35.48	25.87	0.826	0.892
250	12.33	35.00	26.54	0.920	0.798
300	10.70	34.81	26.70	0.995	0.723
400	09.43	34.71	26.84	1.131	0.587
500	07.90	34.61	27.00	1.253	0.465
600	06.78	34.57	27.13	1.362	0.356
700	05.94	34.55	27.23	1.461	0.257
800	05.26	34.54	27.30	1.552	0.166
1000	04.34	34.54	27.41	1.718	0.000

STATION 21

M/V Hugh M. Smith: Cruise 8, 02°00'S, 158°00'W, January 24, 1951. Messenger time: 0840 GCT. Weather: scattered clouds, cumulus. Wind: 120°, 11 kt. Sea: 5-8 ft. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.80	35.35	23.38	4.71	
09	25.82	35.51 1/	23.49 1/	4.81	
26	25.64	35.33	23.41	4.70	
50	25.59	35.29	23.40	4.71	
106	25.44	35.32	23.47	4.66	
191	19.84	35.42	25.14	3.65	
286	10.14	34.77	26.77	2.10	
377	09.63	34.70	26.80	1.72	
474	09.03	34.67	26.88	1.32	
571	07.60	34.61	27.05	2.01	
772	05.72	34.57	27.27	2.02	
973	04.35	34.55	27.41	2.19	
1175	03.70	34.58	27.50		

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.80	35.35	23.38	0.000	1.755
10	25.82	35.34	23.37	0.045	1.710
20	25.80	35.35	23.38	0.090	1.665
30	25.65	35.34	23.42	0.135	1.620
50	25.59	35.29	23.40	0.225	1.530
75	25.53	35.30	23.43	0.338	1.417
100	25.45	35.32	23.47	0.450	1.305
150	25.38	35.32	23.49	0.674	1.081
200	18.21	35.51	25.63	0.846	0.909
250	11.55	34.91	26.62	0.944	0.811
300	10.06	34.75	26.77	1.015	0.740
400	09.54	34.69	26.81	1.149	0.606
500	08.72	34.66	26.92	1.278	0.477
600	07.26	34.60	27.09	1.394	0.361
700	06.33	34.58	27.20	1.497	0.258
800	05.50	34.56	27.29	1.590	0.165
1000	04.23	34.56	27.43	1.755	0.000

1/ Anomalous values.

STATION 22

M/V Hugh M. Smith: Cruise 8, 03°00'S, 157°59'W, January 24, 1951. Messenger time: 1710 GCT. Weather: broken clouds, cumulus. Wind: 110°, 14 kt. Sea: 5-8 ft. Wire angle: 18°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.20	35.50	23.37	4.74	
10	26.16			4.75	
24	26.18	35.48	23.36	4.73	
52	26.16	35.51	23.39	4.67	
104	25.72	35.44	23.47	4.65	
197	17.46	35.49	25.80	3.57	
293	10.60	34.81	26.72	1.72	
394	09.22	34.70	26.87	1.87	
494	08.26	34.63	26.96	1.44	
595	06.88	34.58	27.13	1.55	
798	05.20	34.51	27.29	2.02	
1005	04.40	34.59	27.44	2.24	
1236	03.56	34.61	27.54	2.40	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.20	35.50	23.37	0.000	1.728
10	26.16	35.49	23.36	0.045	1.683
20	26.17	35.48	23.36	0.091	1.637
30	26.18	35.48	23.36	0.136	1.592
50	26.16	35.51	23.39	0.227	1.501
75	26.16	35.51	23.39	0.340	1.388
100	25.97	35.48	23.43	0.453	1.275
150	25.52	35.46	23.55	0.677	1.051
200	15.95	35.35	26.05	0.839	0.889
250	11.85	34.92	26.57	0.929	0.799
300	10.45	34.79	26.73	1.002	0.726
400	09.18	34.70	26.87	1.136	0.592
500	08.13	34.63	26.98	1.258	0.470
600	06.80	34.57	27.13	1.369	0.359
700	05.85	34.53	27.22	1.469	0.259
800	05.19	34.51	27.29	1.562	0.166
1000	04.42	34.59	27.44	1.728	0.000

STATION 23

M/V *Hugh M. Smith*: Cruise 8, 04°00'S, 158°00'W, January 25, 1951. Messenger time: 0123 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 120°, 14 kt. Sea: 5-8 ft. Wire angle: 34°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.00	35.69	23.26	4.72	
09	26.97			4.92	
21	26.80	35.66	23.30	4.72	
46	26.72	35.66	23.33	4.70	
90	26.28	35.54	23.37	4.65	
170	23.86	35.54	24.11	4.64	
249	12.77	34.98	26.44	1.88	
333	09.92	34.79	26.82	1.63	
413	08.87	34.64	26.88	1.82	
495	07.92	34.60	26.99	2.11	
655	06.36	34.56	27.18	2.36	
823	05.12	34.51	27.30	2.22	
1008	04.28	34.52	27.40	2.27	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.00	35.69	23.26	0.000	1.774
10	26.96	35.68	23.26	0.046	1.728
20	26.81	35.66	23.30	0.092	1.682
30	26.77	35.66	23.31	0.138	1.636
50	26.70	35.66	23.33	0.230	1.544
75	26.43	35.58	23.36	0.344	1.430
100	26.24	35.53	23.38	0.458	1.316
150	25.00	35.68	23.88	0.675	1.099
200	21.13	35.69	25.00	0.853	0.921
250	12.75	34.98	26.45	0.970	0.804
300	10.75	34.83	26.71	1.047	0.727
400	09.05	34.65	26.86	1.182	0.592
500	07.87	34.59	26.99	1.304	0.470
600	06.87	34.57	27.12	1.414	0.360
700	05.97	34.55	27.22	1.514	0.260
800	05.26	34.52	27.29	1.606	0.168
1000	04.31	34.52	27.39	1.774	0.000

STATION 24

M/V Hugh M. Smith: Cruise 8, 05°00'S, 158°00'W, January 25, 1951. Messenger time: 0903 GCT. Weather: scattered clouds, no observation. Wind: 120°, 16 kt. Sea: 5-8 ft. Wire angle: 24°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.51	23.31	4.78	
09	26.44				
23	26.42	35.47	23.28	4.76	
51	26.28	35.48	23.33	4.71	
102	26.20	35.46	23.34	4.70	
194	23.47	35.66	24.32	3.82	
284	11.12	34.86	26.66	2.11	
380	09.06	34.69	26.89	1.89	
475	08.03	34.61	26.99	1.90	
572	07.22	34.59	27.09	1.91	
758	05.93	34.54	27.22	2.48	
958	04.53	34.55	27.39	2.23	
1157	03.94	34.56	27.46	2.43	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	26.40	35.51	23.31	0.000	1.861
10	26.44	35.49	23.29	0.046	1.815
20	26.42	35.47	23.28	0.092	1.769
30	26.41	35.48	23.29	0.138	1.723
50	26.29	35.48	23.33	0.230	1.631
75	26.24	35.46	23.33	0.345	1.516
100	26.21	35.46	23.34	0.460	1.401
150	26.16	35.46	23.35	0.690	1.171
200	22.73	35.79	24.63	0.889	0.972
250	14.20	35.12	26.26	1.020	0.841
300	13.00	34.83	26.28	1.112	0.749
400	08.80	34.66	26.90	1.265	0.596
500	07.80	34.60	27.01	1.384	0.477
600	07.03	34.59	27.11	1.494	0.367
700	06.32	34.55	27.18	1.597	0.264
800	05.60	34.54	27.26	1.693	0.168
1000	04.34	34.56	27.42	1.861	0.000

STATION 25

M/V Hugh M. Smith: Cruise 8, 06°01'S, 158°06'W, January 25, 1951. Messenger time: 1708 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 13 kt. Sea: 5-8 ft. Wire angle: 15°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O$_2$ (ml/l)	PO$_4$-P (µg at/l)
02	26.89	35.62	23.24	4.69	
12	26.89	35.63	23.25	4.70	
26	26.90	35.68	23.28	4.69	
55	26.90	35.60	23.22	4.71	
108	26.86	35.62	23.25	4.63	
208	21.94	35.82	24.87	3.74	
307	11.92	34.86	26.51	1.93	
409	08.40	34.62	26.94	2.98	
508	07.24	34.56	27.06	2.76	
609	06.52	34.56	27.16	2.63	
808	05.30	34.50	27.27	2.06	
1013	04.42	34.52	27.38	2.29	
1216	03.76	34.54	27.47	2.55	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(26.90)	(35.62)	23.24	0.000	1.861
10	26.89	35.63	23.25	0.046	1.815
20	26.89	35.65	23.26	0.093	1.768
30	26.90	35.67	23.28	0.139	1.722
50	26.90	35.61	23.23	0.232	1.629
75	26.90	35.61	23.23	0.349	1.512
100	26.87	35.62	23.25	0.466	1.395
150	26.49	35.69	23.42	0.696	1.165
200	22.60	35.87	24.73	0.892	0.969
250	16.90	35.31	25.79	1.032	0.829
300	12.39	34.90	26.45	1.131	0.730
400	08.58	34.63	26.92	1.275	0.586
500	07.30	34.56	27.05	1.391	0.470
600	06.57	34.56	27.15	1.497	0.364
700	05.90	34.53	27.22	1.595	0.266
800	05.33	34.50	27.26	1.689	0.172
1000	04.48	34.52	27.38	1.861	0.000

STATION 26

M/V Hugh M. Smith: Cruise 8, 07°00'S, 158°01'W, January 26, 1951. Messenger time: 0120 GCT. Weather: scattered clouds, cumulus. Wind: 100°, 13 kt. Sea: 5-8 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.50	35.77	23.16	4.69	
09	27.45			4.63	
21	27.38	35.75	23.18	4.59	
46	27.34	35.74	23.19	4.56	
92	27.17	35.74	23.24	4.51	
176	23.64	35.91	24.46	3.85	
258	16.00	35.24	25.95	2.89	
343	10.53	34.79	26.72	1.57	
427	08.70	34.67	26.93	2.39	
513	07.35	34.60	27.08	2.51	
679	05.97	34.51	27.19	2.63	
850	05.20	34.56	27.32	2.05	
1035	04.44	34.54	27.39	2.20	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	27.50	35.77	23.16	0.000	1.837
10	27.44	35.76	23.17	0.047	1.790
20	27.39	35.75	23.18	0.094	1.743
30	27.36	35.74	23.18	0.141	1.696
50	27.29	35.74	23.20	0.236	1.601
75	27.24	35.74	23.22	0.353	1.484
100	27.08	35.74	23.27	0.470	1.367
150	25.22	35.86	23.94	0.687	1.150
200	22.45	35.35	24.76	0.870	0.967
250	16.73	35.30	25.83	1.008	0.829
300	12.53	34.95	26.47	1.106	0.731
400	09.19	34.71	26.38	1.252	0.585
500	07.50	34.61	27.06	1.369	0.468
600	06.52	34.53	27.14	1.475	0.362
700	05.84	34.51	27.21	1.575	0.262
800	05.40	34.54	27.29	1.667	0.170
1000	04.60	34.55	27.39	1.837	0.000

STATION 27

M/V Hugh M. Smith: Cruise 8, 01°50'N, 155°02'W, January 29, 1951. Messenger time: 1955 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 090°, 16 kt. Sea: 5-8 ft. Wire angle: 41°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.40			4.81	
08	25.43	35.09	23.30	4.76	
41	25.40	35.12	23.33	4.75	
77	25.33	35.15	23.38	4.68	
146	24.85	35.24	23.59	4.52	
242	10.96	34.80	26.65	1.92	

STATION 28

M/V Hugh M. Smith: Cruise 8, 03°00'N, 155°04'W, January 30, 1951. Messenger time: 0400 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 15 kt. Sea: 5-8 ft. Wire angle: 43°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	35.08	23.22	4.78	
10	25.63	35.09	23.24	4.78	
44	25.48	35.06	23.26	4.73	
92	25.44	35.10	23.30	4.69	
183	12.86	34.69	26.20	2.02	
290	10.30	34.74	26.72	1.52	

STATION 29

M/V *Hugh M. Smith*: Cruise 8, 03°58'N, 155°04'W, January 30, 1951. Messenger time: 1244 GCT. Weather: no observation. Wind: 090°, 18 kt. Sea: 5-8 ft. Wire angle: 25°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	35.08	22.92	4.69	
12	26.64	35.08	22.91	4.70	
67	26.63	35.08	22.92	4.66	
136	25.06	35.04	23.37	4.19	
277	09.62	34.69	26.79	2.09	
413	08.50	34.64	26.93	1.46	

STATION 30

M/V *Hugh M. Smith*: Cruise 8, 04°57'N, 155°04'W, January 30, 1951. Messenger time: 2022 GCT. Weather: overcast (with breaks), cumulus and altocumulus. Wind: 070°, 21 kt. Sea: 5-8 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	34.99	22.87	4.73	
08	26.58	34.94	22.83	4.71	
48	26.58	34.98	22.86	4.70	
124	25.73	35.16	23.26	4.22	
220	11.86	34.68	26.39	1.11	
321	09.31	34.70	26.85	1.45	

STATION 31

M/V Hugh M. Smith: Cruise 8, 05°59'N, 155°03'W, January 31, 1951. Messenger time: 0422 GCT. Weather: overcast (with breaks), cumulus and nimbostratus. Wind: 070°, 20 kt. Sea: 8-12 ft. Wire angle: 32°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	35.07	22.90	4.75	
15	26.68	35.07	22.89	4.74	
73	26.39	35.13	23.03	4.70	
145	21.08	34.90	24.41	4.04	
295	09.74	34.70	26.78	0.87	
436	08.38	34.62	26.94	1.02	

STATION 32

M/V Hugh M. Smith: Cruise 8, 06°57'N, 154°56'W, January 31, 1951. Messenger time: 1145 GCT. Weather: slight intermittent rain, no observation. Wind: 070°, 24 kt. Sea: 8-12 ft. Wire angle: 05°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
05	26.63	35.14	22.96	4.71	
19	26.64	35.08	22.91	4.72	
79	26.62	35.08	22.92	4.63	
156	16.05	34.66	25.49	3.08	
303	09.48	34.65	26.78	1.09	
442	08.66	34.63	26.90	1.23	

STATION 33

M/V *Hugh M. Smith*: Cruise 8, 05°58'N, 155°08'W, January 31, 1951. Messenger time: 2023 GCT. Weather: overcast (with breaks), cumulus. Wind: 090°, 14 kt. Sea: 8-12 ft. Wire angle: no observations.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.60	35.10	22.94	4.70	
09	26.62	35.03	22.88	4.69	
54	26.62	35.07	22.91	4.68	
110	26.12	35.08	23.08	4.67	
222	11.87	34.66	26.37	1.31	
335	09.52	34.69	26.81	0.83	

STATION 34

M/V *Hugh M. Smith*: Cruise 8, 05°00'N, 155°28'W, February 1, 1951. Messenger time: 0422 GCT. Weather: scattered clouds, cumulus and stratocumulus. Wind: 090°, 19 kt. Sea: 5-8 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.60	34.98	22.85	4.69	
08	26.64	34.99	22.85	4.69	
53	26.60	34.99	22.86	4.69	
107	26.35	35.02	22.96	4.61	
215	12.24	34.64	26.28	1.00	
323	09.44	34.68	26.81	1.02	

STATION 35

M/V *Hugh M. Smith*: Cruise 8, 04°04'N, 155°46'W, February 1, 1951. Messenger time: 1201 GCT. Weather: scattered clouds, no observation. Wind: 140°, 19 kt. Sea: 5-8 ft. Wire angle: 24°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	35.08	22.92	4.69	
08	26.62	35.06	22.91	4.70	
51	26.64	35.08	22.91	4.66	
105	26.14	35.02	23.03	4.52	
209	12.46	34.65	26.25	1.65	
316	09.30	34.69	26.85	1.59	

STATION 36

M/V *Hugh M. Smith*: Cruise 8, 03°06'N, 156°09'W, February 1, 1951. Messenger time: 2024 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 100°, 18 kt. Sea: 5-8 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	35.10	22.97	4.70	
11	26.52	35.13	22.99	4.70	
52	26.44	35.09	22.98	4.70	
106	25.56	35.11	23.27	4.45	
223	11.18	34.72	26.54	2.36	
346	10.01	34.71	26.74	2.12	

STATION 37

M/V *Hugh M. Smith*: Cruise 8, 02°07'N, 156°33'W, February 2, 1951. Messenger time: 0414 GCT. Weather: scattered clouds, cumulus. Wind: 110°, 14 kt. Sea: 5-8 ft. Wire angle: 39°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.60	35.15	23.28	4.74	
08	25.63	35.20	23.32	4.78	
44	25.46	35.18	23.36	4.77	
84	25.44	35.15	23.34	4.75	
162	23.40	35.04	23.87	4.00	
250	10.92	34.75	26.62	2.11	

STATION 38

M/V *Hugh M. Smith*: Cruise 8, 02°59'N, 156°43'W, February 2, 1951. Messenger time: 1126 GCT. Weather: scattered clouds, no observation. Wind: 080°, 17 kt. Sea: 5-8 ft. Wire angle: 36°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.50	35.11	22.97	4.69	
12	26.54	35.14	22.99	4.65	
61	26.54	35.10	22.96	4.66	
119	25.76	35.10	23.20	4.22	
232	10.78	34.77	26.65	1.65	
365	09.72	34.71	26.79	1.46	

STATION 39

M/V Hugh M. Smith: Cruise 8, 04°02'N, 157°02'W, February 2, 1951. Messenger time: 1850 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 090°, 15 kt. Sea: 3-5 ft. Wire angle: 38°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	35.09	22.95	4.67	
12	26.54	35.08	22.95	4.67	
59	26.54	35.12	22.97	4.67	
110	25.86	35.07	23.15	4.37	
206	11.22	34.71	26.53	0.97	
323	09.18	34.69	26.87	1.64	

STATION 40

M/V Hugh M. Smith: Cruise 8, 05°04'N, 157°17'W, February 3, 1951. Messenger time: 0211 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: 18°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.60	35.11	22.93	4.70	
09	26.64	35.12	22.94	4.70	
57	26.50	35.12	22.99	4.69	
113	26.46	35.12	23.00	4.68	
227	11.01	34.72	26.56	0.82	
345	09.03	34.69	26.89	1.50	

STATION 41

M/V Hugh M. Smith: Cruise 8, 05°58'N, 157°26'W, February 3, 1951. Messenger time: 0826 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 18 kt. Sea: 5-8 ft. Wire angle: < 5°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
06	26.64	35.16	22.97	4.76	
16	26.63	35.18	22.99	4.74	
66	26.58	35.18	23.01	4.74	
125	26.48	35.17	23.03	4.63	
241	10.58	34.69	26.63	0.92	
357	08.81	34.66	26.90	1.00	

STATION 42

M/V Hugh M. Smith: Cruise 8, 06°50'N, 157°33'W, February 3, 1951. Messenger time: 1550 GCT. Weather: broken clouds, cumulus. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: < 5°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
10	26.70	35.05	22.87	4.70	
20	26.72	35.07	22.88	4.72	
70	26.68	35.19	22.98	4.70	
131	21.04	34.87	24.40	3.59	
247	10.21	34.68	26.69	0.65	
363	09.07	34.62	26.83	0.93	

STATION 43

M/V Hugh M. Smith: Cruise 8, 06°00'N, 157°53'W, February 3, 1951. Messenger time: 2319 GCT. Weather: slight intermittent rain, cumulus. Wind: 100°, 15 kt. Sea: 8-12 ft. Wire angle: <5°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
06	26.66	35.19	22.99	4.70	
16	26.62	35.19	23.00	4.72	
67	26.54	35.19	23.03	4.71	
126	24.28	35.08	23.64	3.91	
245	10.58	34.67	26.61	0.67	
363	08.88	34.64	26.88	0.96	

STATION 44

M/V Hugh M. Smith: Cruise 8, 05°00'N, 158°34'W, February 4, 1951. Messenger time: 0827 GCT. Weather: scattered clouds, cumulus. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: no observation

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	35.20	23.05	4.73	
09	26.51	35.17	23.02	4.73	
60	26.50	35.18	23.03	4.70	
118	26.49	35.18	23.04	4.68	
230	11.54	34.65	26.42	1.11	
351	09.18	34.63	26.82	1.59	

STATION 45

M/V Hugh M. Smith: Cruise 8, 04°05'N, 158°53'W, February 4, 1951. Messenger time: 1644 GCT. Weather: overcast (with breaks), cumulus. Wind: 060°, 18 kt. Sea: 5-8 ft. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.11	23.02	4.73	
14	26.36	35.11	23.02	4.73	
67	26.28	35.07	23.02	4.73	
127	26.10	35.16	23.14	4.52	
255	10.46	34.66	26.63	1.37	
391	08.78	34.64	26.89	1.58	

STATION 46

M/V Hugh M. Smith: Cruise 8, 03°03'N, 159°10'W, February 6, 1951. Messenger time: 1420 GCT. Weather: scattered clouds, no observation. Wind: 090°, 16 kt. Sea: 5-8 ft. Wire angle: 46°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.11	23.00	4.70	
11	26.44	35.10	22.99	4.73	
50	26.30	35.09	23.03	4.71	
92	25.94	35.10	23.15	4.72	
159	16.64	34.77	25.44	2.59	
264	10.00	34.70	26.74	2.56	

STATION 47

M/V Hugh M. Smith: Cruise 8, 01°57'N, 159°39'W, February 6, 1951. Messenger time: 2322 GCT. Weather: scattered clouds, cumulus and altostratus. Wind: 100°, 15 kt. Sea: 5-8 ft. Wire angle: 43°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.20	35.11	23.09	4.69	
10	26.14	35.12	23.10	4.71	
52	25.96	35.12	23.16	4.68	
98	25.04	35.09	23.42	4.18	
193	11.16	34.72	26.55	2.51	
311	10.22	34.75	26.74	1.66	

STATION 48

M/V Hugh M. Smith: Cruise 8, 03°00'N, 159°47'W, February 7, 1951. Messenger time: 0003 GCT. Weather: scattered clouds, cumulus and altocumulus. Wind: 080°, 15 kt. Sea: 5-8 ft. Wire angle: 44°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	35.13	23.06	4.74	
11	26.31	35.10	23.03	4.74	
48	26.24	35.10	23.05	4.73	
88	26.12	35.10	23.09	4.72	
170	15.70	34.71	25.61	2.55	
266	10.05	34.81	26.81	1.68	

STATION 49

M/V *Hugh M. Smith*: Cruise 8, 04°06'N, 160°06'W, February 7, 1951. Messenger time: 1625 GCT. Weather: overcast (with breaks), cumulus. Wind: 080°, 18 kt. Sea: 5-8 ft. Wire angle: 26°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.27	23.13	4.66	
13	26.43	35.19	23.06	4.69	
65	26.41	35.20	23.08	4.69	
130	26.18	35.18	23.13	4.65	
269	09.59	34.65	26.77	2.42	
408	08.59	34.62	26.91	1.76	

STATION 50

M/V *Hugh M. Smith*: Cruise 8, 04°58'N, 160°36'W, February 8, 1951. Messenger time: 0523 GCT. Weather: scattered clouds, cumulus. Wind: 070°, 18 kt. Sea: 5-8 ft. Wire angle: 16°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
03	27.33	34.94	22.59		
12	27.34	34.91	22.56	4.72	
59	27.28	34.92	22.59	4.71	
117	26.24	34.90	22.90	4.45	
232	10.46	34.64	26.61	1.30	
351	08.90	34.65	26.88	1.64	

STATION 51

M/V *Hugh M. Smith*: Cruise 8, 05°57'N, 160°53'W, February 8, 1951. Messenger time: 1250 GCT. Weather: scattered clouds, no observation. Wind: 060°, 19 kt. Sea: 5-8 ft. Wire angle: 11°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
03	27•19	34•90	22•60	4•73	
13	27•22	34•87	22•57	4•73	
61	27•22	34•90	22•60	4•71	
121	25•28	35•11	23•36	4•17	
235	09•90	34•67	26•73	1•30	
355	08•77	34•63	26•39	1•63	

STATION 52

M/V *Hugh M. Smith*: Cruise 8, 06°59'N, 161°12'W, February 8, 1951. Messenger time: 2110 GCT. Weather: broken clouds, cumulus. Wind: 050°, 19 kt. Sea: 8-12 ft. Wire angle: no observation

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
06	26•96	35•05	22•79	4•69	
16	26•96	35•05	22•79	4•69	
66	26•94	35•05	22•79	4•69	
125	20•32	34•86	24•59	3•67	
241	10•68	34•68	26•60	0•58	
356	08•92	34•65	26•88	1•07	

STATION 53

M/V *Hugh M. Smith*: Cruise 8, 05°55'N, 161°27'W, February 9, 1951. Messenger time: 0450 GCT. Weather: heavy intermittent rain, cumulus. Wind: 080°, 19 kt. Sea: 8-12 ft. Wire angle: 21°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	27.18	34.96	22.65	4.72	
12	27.20	34.94	22.63	4.74	
58	27.02	35.01	22.74	4.71	
114	25.33	35.05	23.30	4.13	
225	11.00	34.61	26.49	1.04	
342	09.09	34.62	26.83	1.52	

STATION 54

M/V *Hugh M. Smith*: Cruise 8, 04°52'N, 161°48'W, February 9, 1951. Messenger time: 1523 GCT. Weather: scattered clouds, no observation. Wind: 080°, 22 kt. Sea: 8-12 ft. Wire angle: 23°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.20	34.96	22.66	4.73	
14	27.16	34.97	22.67	4.71	
69	27.15	34.96	22.66	4.69	
141	24.64	35.00	23.47	3.97	
281	09.62	34.64	26.75	1.70	
419	08.75	34.63	26.89	1.61	

STATION 55

M/V *Hugh M. Smith*: Cruise 8, 03°58'N, 162°02'W, February 9, 1951. Messenger time: 2230 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 20 kt. Sea: 8-12 ft. Wire angle: 42°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.20	35.00	22.67	4.67	
12	27.22	35.02	22.68	4.67	
54	27.12	35.07	22.76	4.65	
113	26.40	35.19	23.07	4.66	
224	10.60	34.69	26.62	1.28	
343	08.95	34.64	26.86	1.79	

STATION 56

M/V *Hugh M. Smith*: Cruise 8, 02°58'N, 162°25'W, February 10, 1951. Messenger time: 0607 GCT. Weather: broken clouds, cumulus. Wind: 090°, 14 kt. Sea: 8-12 ft. Wire angle: 52°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.21	23.07	4.76	
10	26.44	35.19	23.06	4.77	
43	26.16	35.17	23.13	4.78	
80	25.83	35.14	23.21	4.77	
147	25.56	35.15	23.30	4.74	
226	10.80	34.78	26.66	2.45	

STATION 57

M/V *Hugh M. Smith*: Cruise 8, 02°00'N, 162°57'W, February 10, 1951. Messenger time: 1349 GCT. Weather: scattered clouds, no observation. Wind: 120°, 17 kt. Sea: 8-12 ft. Wire angle: 45°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.50	35.12	23.29	4.78	
11	25.54	35.12	23.29	4.80	
49	25.54	35.10	23.27	4.77	
92	25.46	35.13	23.32	4.74	
173	16.16	34.75	25.54	2.62	
266	10.53	34.77	26.70	2.15	

STATION 58

M/V *Hugh M. Smith*: Cruise 8, 03°08'N, 163°15'W, February 10, 1951. Messenger time: 2223 GCT. Weather: slight intermittent drizzle, cumulus and cumulonimbus. Wind: 100°, 20 kt. Sea: 8-12 ft. Wire angle: 43°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.90	35.13	23.19	4.87	
11	25.88	35.10	23.16	4.85	
49	25.77	35.12	23.21	4.84	
90	25.68	35.14	23.26	4.85	
169	23.36	35.07	23.91	3.91	
262	10.12	34.73	26.74	2.51	

STATION 59

M/V *Hugh M. Smith*: Cruise 8, 04°02'N, 163°58'W, February 11, 1951. Messenger time: 0540 GCT. Weather: broken clouds, cumulus. Wind: 100°, 13 kt. Sea: 8-12 ft. Wire angle: 36°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	35.13	23.13	4.81	
12	26.08	35.14	23.14	4.81	
56	25.88	35.20	23.24	4.79	
113	25.91	35.21	23.24	4.74	
235	10.56	34.64	26.59	1.64	
364	08.84	34.66	26.90	1.91	

STATION 60

M/V *Hugh M. Smith*: Cruise 8, 04°57'N, 164°32'W, February 11, 1951. Messenger time: 1253 GCT. Weather: scattered clouds, no observation. Wind: 080°, 10 kt. Sea: 8-12 ft. Wire angle: 08°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.90	35.04	22.78	4.71	
15	27.00	35.10	22.81	4.70	
75	27.00	35.11	22.82	4.67	
151	23.45	35.04	23.85	3.69	
299	09.63	34.70	26.80	1.56	
439	08.43	34.64	26.95	1.20	

STATION 61

M/V Hugh M. Smith: Cruise 8, 05°56'N, 165°05'W, February 11, 1951. Messenger time: 2051 GCT. Weather: overcast (with breaks) cumulus. Wind: 100°, 14 kt. Sea: 8-12 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.20	34.66	22.42	4.70	
10	27.22	34.56	22.34	4.72	
58	27.04	34.88	22.64	4.57	
113	25.90	35.09	23.15	4.11	
228	11.72	34.63	26.37	1.30	
343	09.17	34.66	26.85	1.37	

STATION 62

M/V *Hugh M. Smith*: Cruise 8, 06°44'N, 165°23'W, February 12, 1951. Messenger time: 0310 GCT. Weather: slight intermittent rain, nimbostratus. Wind: 070°, 24 kt. Sea: 12 to 20 ft. Wire angle: <05°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
06	27.21	34.85	22.56	4.74	
16	27.22	34.82	22.54	4.72	
36	27.24	34.87	22.56	4.70	
67	27.24	34.83	22.53	4.65	
127	23.82	35.06	23.76	3.78	
244	10.43	34.68	26.65	0.66	
363	08.98	34.62	26.84	1.14	
476	07.98	34.55	26.94	0.97	
588	06.96	34.56	27.10	0.87	
701	06.10	34.49	27.16	1.11	
934	04.86	34.51	27.33	1.39	
1151	04.06	34.52	27.42	1.72	
1369	03.42	34.55	27.51	1.90	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	(27.20)	(34.85)	22.56	0.000	1.796
10	27.21	34.84	22.55	0.053	1.743
20	27.22	34.84	22.55	0.106	1.690
30	27.23	34.85	22.55	0.159	1.637
50	27.24	34.85	22.55	0.266	1.530
75	27.23	34.85	22.55	0.399	1.397
100	26.97	34.96	22.72	0.530	1.266
150	22.12	34.97	24.18	0.755	1.041
200	12.75	34.58	26.14	0.898	0.898
250	10.32	34.68	26.67	0.983	0.813
300	09.66	34.66	26.76	1.053	0.743
400	08.65	34.60	26.88	1.183	0.613
500	07.75	34.55	26.98	1.304	0.492
600	06.86	34.55	27.10	1.416	0.380
700	06.10	34.49	27.16	1.520	0.276
800	05.52	34.49	27.23	1.618	0.178
1000	04.59	34.51	27.36	1.796	0.000

STATION 63

M/V *Hugh M. Smith*: Cruise 8, 05°51'N, 165°28'W, February 12, 1951. Messenger time: 1040 GCT. Weather: slight intermittent drizzle, cumulus. Wind: 090°, 19 kt. Sea: 8-12 ft. Wire angle: 18°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.20	34.72	22.46	4.67	
09	27.20	34.75	22.49	4.68	
29	27.22	34.70	22.45	4.68	
57	27.16	34.91	22.62	4.60	
116	25.92	35.07	23.13	4.08	
233	11.54	34.60	26.38	1.55	
341	09.48	34.72	26.84	1.39	
454	08.32	34.63	26.95	1.17	
565	07.20	34.58	27.08	0.86	
674	06.35	34.52	27.15	0.95	
899	04.86	34.52	27.33	1.45	
1116	04.10	34.52	27.42	1.61	
1324	03.49	34.59	27.53	1.88	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.20	34.72	22.46	0.000	1.836
10	27.20	34.74	22.48	0.054	1.782
20	27.21	34.72	22.46	0.108	1.728
30	27.22	34.70	22.44	0.162	1.674
50	27.18	34.84	22.56	0.269	1.567
75	27.07	34.95	22.68	0.401	1.435
100	26.86	35.00	22.78	0.530	1.306
150	24.26	35.06	23.63	0.766	1.070
200	14.78	34.64	25.76	0.932	0.904
250	11.08	34.65	26.51	1.029	0.807
300	10.10	34.72	26.74	1.104	0.732
400	08.88	34.67	26.90	1.235	0.601
500	07.83	34.61	27.01	1.354	0.482
600	06.93	34.56	27.10	1.464	0.372
700	06.20	34.52	27.17	1.567	0.269
800	05.48	34.52	27.26	1.663	0.173
1000	04.43	34.52	27.38	1.836	0.000

STATION 64

M/V Hugh M. Smith: Cruise 8, 04°58'N, 165°35'W, February 12, 1951. Messenger time: 1825 GCT. Weather: overcast (with breaks), cumulus. Wind: 060°, 18 kt. Sea: 8-12 ft. Wire angle: 20°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.90	35.12	22.86	4.71	
09	26.89	35.07	22.83	4.69	
28	26.90	35.10	22.85	4.71	
58	26.91	35.13	22.87	4.67	
115	26.28	35.17	23.09	4.34	
227	13.19	34.51	26.00	2.48	
337	09.30	34.68	26.84	1.06	
444	08.38	34.60	26.92	1.10	
554	07.38	34.59	27.06	1.10	
663	06.46	34.52	27.14	1.17	
882	05.03	34.53	27.32	1.30	
882	05.22	34.53	27.30		
1097	04.11	34.54	27.43	1.63	
1308	03.48	34.56	27.51	1.84	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.90	35.12	22.86	0.000	1.893
10	26.89	35.08	22.83	0.050	1.843
20	26.89	35.09	22.84	0.101	1.792
30	26.90	35.11	22.85	0.151	1.742
50	26.91	35.12	22.86	0.251	1.642
75	26.90	35.14	22.88	0.377	1.516
100	26.83	35.14	22.90	0.503	1.390
150	26.18	35.17	23.13	0.748	1.145
200	18.90	34.81	24.92	0.946	0.947
250	12.10	34.50	26.20	1.071	0.822
300	10.08	34.69	26.72	1.153	0.740
400	08.75	34.62	26.88	1.286	0.607
500	07.88	34.60	27.00	1.407	0.486
600	06.99	34.56	27.09	1.518	0.375
700	06.20	34.51	27.16	1.622	0.271
800	05.59	34.52	27.25	1.719	0.174
1000	04.54	34.54	27.38	1.893	0.000

STATION 65

M/V *Hugh M. Smith*: Cruise 8, 03°59'N, 166°01'W, February 13, 1951. Messenger time: 0235 GCT. Weather: broken clouds, cumulus, stratocumulus, cirrostratus, and cirrus. Wind: 090°, 17 kt. Sea: 5-8 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.10	35.19	22.85	4.71	
09	27.09				
23	27.04	35.10	22.80	4.72	
45	26.98	35.12	22.83	4.71	
86	26.43	35.21	23.08	4.56	
159	25.28	35.13	23.37	4.72	
232 1/	12.60	34.83	26.36	2.95	
301	09.48	34.69	26.82	1.96	
374	08.91	34.60	26.84	1.77	
446	08.46	34.60	26.91	1.87	
593	07.34	34.55	27.04	1.20	
752	05.99	34.52	27.20	1.45	
934	04.85	34.54	27.35	1.71	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.10	35.19	22.85	0.000	1.859
10	27.08	35.14	22.82	0.050	1.809
20	27.05	35.11	22.81	0.101	1.758
30	27.02	35.10	22.81	0.152	1.707
50	26.89	35.15	22.89	0.252	1.607
75	26.52	35.20	23.04	0.376	1.483
100	26.40	35.20	23.08	0.497	1.362
150	25.40	35.14	23.35	0.733	1.126
200	17.95	34.78	25.13	0.921	0.938
250	11.41	34.56	26.38	1.036	0.823
300	09.51	34.69	26.81	1.112	0.747
400	08.74	34.60	26.87	1.241	0.618
500	08.06	34.58	26.96	1.364	0.495
600	07.30	34.55	27.04	1.480	0.379
700	06.40	34.53	27.15	1.587	0.272
800	05.65	34.52	27.24	1.686	0.173
1000	(04.55)	(34.56)	27.40	1.859	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 66

M/V Hugh M. Smith: Cruise 8, 03°00'N, 166°36'W, February 13, 1951. Messenger time: 1118 GCT. Weather: scattered clouds, no observation. Wind: 090°, 19 kt. Sea: 5-8 ft. Wire angle: 57°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	35.26	23.13	4.77	
10	26.42	35.27	23.13		
21	26.42	35.25	23.11		
44	26.42	35.26	23.12	4.77	
78	25.90	35.25	23.27	4.77	
130	25.82	35.24	23.29	4.74	
179 1/	18.98	35.26	25.24		
236	10.91	34.62	26.52	2.06	
287	10.10	34.75	26.76	2.39	
340	09.80	34.72	26.79	1.76	
431	08.84	34.68	26.91	2.07	
578	07.50	34.61	27.06	1.30	
719	06.00	34.53	27.20	1.49	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	26.40	35.26	23.13	0.000	1.780
10	26.42	35.27	23.13	0.048	1.732
20	26.42	35.25	23.11	0.095	1.635
30	26.42	35.25	23.11	0.143	1.637
50	26.39	35.25	23.12	0.239	1.541
75	25.93	35.25	23.26	0.356	1.424
100	25.86	35.24	23.28	0.473	1.307
150	25.77	35.23	23.30	0.705	1.075
200	15.00	34.69	25.75	0.879	0.901
250	10.63	34.67	26.60	0.974	0.806
300	10.02	34.74	26.77	1.046	0.734
400	09.19	34.69	26.86	1.177	0.603
500	08.23	34.65	26.98	1.299	0.481
600	07.29	34.60	27.08	1.412	0.368
700	06.17	34.54	27.19	1.516	0.264
800	(05.31)	(34.52)	27.28	1.610	0.170
1000	(04.40)	(34.52)	27.38	1.780	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values of this level except temperature are probably in error.

STATION 67

M/V Hugh M. Smith: Cruise 8, 02°04'N, 166°47'W, February 13, 1951. Messenger time: 1904 GCT. Weather: scattered clouds, cumulus and stratocumulus. Wind: 090°, 17 kt. Sea: 5-8 ft. Wire angle: 55°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.65	35.22	23.33	4.74	
09	25.67				
21	25.66			4.77	
44	25.67	35.20	23.30	4.73	
86	25.66	35.19	23.30	4.75	
156	23.91			4.77	
221	10.94	34.77	26.63	2.58	
289	10.45	34.76	26.71	1.70	
357	10.00	34.73	26.76	1.87	
433	09.24	34.67	26.84	1.49	
581	07.37	34.57	27.05	1.46	
735	05.82	34.56	27.25	1.54	
946	04.52	34.52	27.37	1.93	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.60	35.22	23.33	0.000	1.740
10	25.67	35.22	23.32	0.046	1.694
20	25.66	35.21	23.32	0.091	1.649
30	25.66	35.21	23.32	0.137	1.603
50	25.67	35.20	23.31	0.229	1.511
75	25.66	35.19	23.30	0.344	1.396
100	25.66	35.19	23.30	0.460	1.280
150	25.30	35.18	23.41	0.689	1.051
200	11.86	34.62	26.34	0.846	0.894
250	10.72	34.77	26.67	0.926	0.814
300	10.40	34.76	26.71	0.997	0.743
400	09.61	34.69	26.80	1.134	0.606
500	08.40	34.62	26.94	1.262	0.478
600	07.15	34.57	27.08	1.378	0.362
700	06.14	34.56	27.21	1.480	0.260
800	05.30	34.54	27.30	1.573	0.167
1000	(04.34)	(34.52)	27.39	1.740	0.000

STATION 68

M/V Hugh M. Smith: Cruise 8, 01°02'N, 167°02'W, February 14, 1951. Messenger time: first cast, 0344 GCT; second cast, 0641 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 15 kt. Sea: 5-8 ft. Wire angle: first cast, 58°, second cast, 62°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.90	35.24	23.27	4.82	
09	25.95	35.21	23.23	4.81	
19	25.90	35.20	23.24	4.86	
39	25.74	35.21	23.29	4.82	
70	25.64	35.19	23.31	4.74	
121	24.45	35.11	23.61	4.37	
172	17.06	34.79	25.36	2.95	
221	12.19	34.73	26.36	2.97	
270	11.50	34.83	26.57	2.74	
338	10.51	34.78	26.71	1.76	
517	07.80	34.59	27.00	1.41	
709	06.05	34.53	27.20	1.83	
907	05.10	34.54	27.32	2.07	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.90	35.24	23.27	0.000	1.712
10	25.95	35.21	23.23	0.046	1.666
20	25.90	35.20	23.24	0.093	1.619
30	25.80	35.21	23.28	0.139	1.573
50	25.70	35.21	23.31	0.232	1.480
75	25.63	35.19	23.31	0.347	1.365
100	24.80	35.14	23.53	0.459	1.253
150	21.27	34.97	24.42	0.659	1.053
200	13.15	34.68	26.13	0.797	0.915
250	11.76	34.81	26.51	0.885	0.827
300	11.08	34.82	26.64	0.962	0.750
400	09.50	34.70	26.82	1.102	0.610
500	08.00	34.60	26.98	1.227	0.485
600	06.95	34.55	27.09	1.339	0.373
700	06.12	34.54	27.20	1.441	0.271
800	05.50	34.54	27.27	1.536	0.176
1000	(04.94)	(34.54)	27.34	1.712	0.000

STATION 69

M/V *Hugh M. Smith*: Cruise 8, 00°01'N, 167°23'W, February 14, 1951. Messenger time: 1256 GCT. Weather: scattered clouds, no observation. Wind: 100°, 15 kt. Sea: 5-8 ft. Wire angle: 58°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.50	35.26	23.41	4.70	
09	25.48	35.26	23.41	4.72	
19	25.50	35.26	23.40	4.73	
40	25.45	35.27	23.43	4.73	
67	25.32	35.26	23.46	4.65	
117	24.82	35.26	23.61	4.21	
165	22.99	35.81	24.57	3.34	
220	14.59	35.16	26.20	3.19	
281	11.66	34.88	26.58	2.97	
347	10.58	34.78	26.70	1.86	
485	08.39	34.63	26.94	1.61	
625	06.78	34.54	27.11	1.70	
798	05.36	34.52	27.27	2.05	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	25.50	35.26	23.41	0.000	1.723
10	25.48	35.26	23.41	0.045	1.678
20	25.50	35.26	23.41	0.090	1.633
30	25.48	35.26	23.41	0.135	1.588
50	25.40	35.27	23.44	0.224	1.499
75	25.28	35.26	23.47	0.336	1.387
100	25.07	35.26	23.54	0.447	1.276
150	22.94	35.38	24.26	0.650	1.073
200	16.70	35.35	25.87	0.798	0.925
250	12.80	34.99	26.44	0.895	0.828
300	11.30	34.85	26.62	0.974	0.749
400	09.70	34.71	26.80	1.116	0.607
500	08.19	34.61	26.96	1.242	0.481
600	07.04	34.54	27.07	1.357	0.366
700	06.06	34.53	27.20	1.460	0.263
800	(05.31)	(34.52)	27.28	1.554	0.169
1000	(04.35)	(34.52)	27.39	1.723	0.000

STATION 70

M/V *Hugh M. Smith*: Cruise 8, 01°05'S, 167°36'W, February 14, 1951. Messenger time: first cast, 2112 GCT; second cast, 2158 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 090°, 15 kt. Sea: 5-8 ft. Wire angle: first cast, 44°; second cast, 56°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O2 (ml/l)	PO4-P (µg at/l)
00	25.85	35.39	23.40	4.65	
12	25.84	35.39	23.40	4.67	
26	25.84	35.38	23.39	4.67	
52	25.82	35.36	23.38	4.75	
100	25.82	35.37	23.39	4.70	
189	16.46	35.32	25.91	2.70	
278	11.52	34.85	26.58	2.69	
377	10.13	34.75	26.75	2.07	
470	08.76	34.65	26.90	1.52	
571	07.64	34.57	27.01	1.90	
771	05.95	34.52	27.20	1.92	
977	04.72	34.49	27.32	2.24	
1195	03.85	34.52	27.44	1.83	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	25.80	35.39	23.40	0.000	1.778
10	25.84	35.39	23.40	0.045	1.733
20	25.84	35.38	23.39	0.090	1.688
30	25.84	35.38	23.39	0.135	1.643
50	25.82	35.36	23.38	0.226	1.552
75	25.82	35.36	23.38	0.339	1.439
100	25.82	35.37	23.39	0.452	1.326
150	25.30	35.44	23.60	0.675	1.103
200	15.25	35.20	26.09	0.834	0.944
250	12.01	34.90	26.53	0.923	0.855
300	11.22	34.82	26.61	1.000	0.778
400	09.81	34.72	26.79	1.143	0.635
500	08.38	34.62	26.94	1.271	0.507
600	07.40	34.56	27.04	1.389	0.389
700	06.54	34.54	27.14	1.497	0.281
800	05.76	34.51	27.22	1.597	0.181
1000	04.60	34.49	27.34	1.778	0.000

STATION 71

M/V Hugh M. Smith: Cruise 8, 02°01'S, 167°42'W, February 15, 1951. Messenger time: 0525 GCT. Weather: broken clouds, cumulus, stratocumulus and cirrus. Wind: 070°, 17 kt. Sea: 5-8 ft. Wire angle: 55°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.00	35.24	23.24	4.82	
11	25.98	35.22	23.23	4.84	
21	25.94			4.84	
42	25.92	35.26	23.28	4.82	
76	25.90	35.25	23.27	4.83	
130	25.61	35.26	23.37	4.61	
178	21.02	35.72	25.05	3.37	
229	12.86	35.23 1/	26.62 1/	2.71	
275	10.62	34.79	26.70	2.47	
329	10.12	34.71	26.73	1.78	
435	09.30	34.67	26.83	1.68	
547	08.09	34.60	26.97	1.91	
693	06.46	34.54	27.15	1.99	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.00	35.24	23.24	0.000	1.788
10	25.98	35.22	23.23	0.047	1.741
20	25.95	35.23	23.24	0.093	1.695
30	25.93	35.24	23.26	0.140	1.648
50	25.92	35.26	23.28	0.232	1.556
75	25.90	35.25	23.27	0.348	1.440
100	25.84	35.25	23.29	0.464	1.324
150	25.42	35.33	23.48	0.692	1.096
200	15.58	35.20	26.01	0.855	0.933
250	11.30	34.86	26.63	0.944	0.844
300	10.38	34.74	26.70	1.016	0.772
400	09.60	34.69	26.80	1.154	0.634
500	08.64	34.63	26.91	1.283	0.505
600	07.41	34.57	27.04	1.402	0.386
700	(06.40)	(34.54)	27.16	1.509	0.279
800	(05.67)	(34.51)	27.23	1.608	0.180
1000	(04.60)	(34.49)	27.34	1.788	0.000

1/ Anomalous value.

STATION 72

M/V *Hugh M. Smith*: Cruise 8, 03°05'S, 167°50'W, February 15, 1951. Messenger time: 1339 GCT. Weather: scattered clouds, no observation. Wind: 100°, 16 kt. Sea: 5-8 ft. Wire angle: 41°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.39	23.22	4.80	
12	26.37	35.39	23.23	4.79	
27	26.38	35.41	23.24	4.79	
55	26.34	35.41	23.26	4.74	
108	26.12	35.38	23.30	4.76	
211	18.89	35.52	25.46	2.88	
294	10.71	34.81	26.70	2.63	
399	09.18	34.69	26.87	1.98	
399	09.24	34.69	26.86		
499	08.47	34.64	26.94	1.80	
612	07.24	34.57	27.07	1.68	
844	05.16	34.51	27.29	2.16	
1090	04.14	34.52	27.41	2.29	
1354	03.39	34.55	27.51	2.60	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.40	35.39	23.22	0.000	1.827
10	26.37	35.39	23.23	0.047	1.780
20	26.37	35.40	23.24	0.093	1.734
30	26.37	35.41	23.25	0.140	1.687
50	26.35	35.41	23.25	0.233	1.594
75	26.34	35.41	23.26	0.349	1.478
100	26.22	35.40	23.29	0.465	1.362
150	25.92	35.52	23.47	0.693	1.134
200	20.00	35.63	25.26	0.875	0.952
250	14.01	35.05	26.24	0.991	0.836
300	10.55	34.79	26.71	1.073	0.754
400	09.20	34.69	26.86	1.207	0.620
500	08.47	34.64	26.94	1.332	0.495
600	07.39	34.58	27.05	1.448	0.379
700	06.35	34.53	27.16	1.555	0.272
800	05.50	34.51	27.25	1.652	0.175
1000	04.48	34.51	27.37	1.827	0.000

STATION 73

M/V Hugh M. Smith: Cruise 8, 04°00'S, 167°58'W, February 15, 1951. Messenger time: 2106 GCT. Weather: scattered clouds, cumulus. Wind: 090°, 15 kt. Sea: 5-8 ft. Wire angle: 30°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.90	35.56	23.19	4.74	
08	26.86	35.55	23.20	4.75	
25	26.88	35.56	23.20	4.76	
50	26.88	35.57	23.21	4.73	
100	26.88	35.58	23.21	4.74	
193	21.42	35.95	25.12	3.55	
278	11.68	34.89	26.58	2.16	
366	09.44	34.73	26.86	1.89	
460	08.40	34.66	26.96	1.93	
552	07.42	34.61	27.07	1.75	
743	05.76	34.53	27.23	2.16	
932	04.72	34.52	27.35	2.33	
1124	04.06	34.54	27.44	2.44	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.90	35.56	23.19	0.000	1.810
10	26.86	35.55	23.20	0.047	1.763
20	26.87	35.56	23.20	0.094	1.716
30	26.88	35.56	23.20	0.141	1.669
50	26.88	35.57	23.21	0.235	1.575
75	26.88	35.58	23.21	0.352	1.458
100	26.88	35.58	23.21	0.470	1.340
150	26.62	35.62	23.33	0.703	1.107
200	20.80	35.88	25.24	0.889	0.921
250	13.50	35.04	26.34	1.004	0.806
300	10.88	34.83	26.68	1.083	0.727
400	09.00	34.70	26.90	1.217	0.593
500	08.00	34.64	27.01	1.336	0.474
600	06.93	34.58	27.12	1.446	0.364
700	06.07	34.54	27.20	1.547	0.263
800	05.41	34.53	27.28	1.640	0.170
1000	04.42	34.53	27.39	1.810	0.000

STATION 74

M/V *Hugh M. Smith*: Cruise 8, 05°03'S, 168°09'W, February 16, 1951. Messenger time: 0445 GCT. Weather: broken clouds, cumulus, stratocumulus and cirrus. Wind: 090°, 13 kt. Sea: 5-8 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.52	35.69	23.09	4.65	
09	27.54	25.69	23.08	4.65	
25	27.42	35.69	23.12	4.66	
48	27.38	35.69	23.14	4.66	
94	27.36	35.68	23.14	4.64	
179	24.23	36.17	24.48	3.67	
261	13.26	35.01	26.37	2.17	
340	09.66	34.75	26.83	2.29	
423	08.95	34.66	26.88	2.18	
505	07.98	34.61	26.99	1.83	
687	06.42	34.54	27.16	1.70	
871	05.38	34.54	27.29	2.07	
1060	04.55	34.52	27.37	2.28	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	ΔD1000-ΔD (dyn. m)
00	27.50	35.69	23.10	0.000	1.882
10	27.54	35.69	23.08	0.048	1.834
20	27.47	35.69	23.11	0.096	1.786
30	27.41	35.69	23.13	0.144	1.738
50	27.38	35.69	23.14	0.239	1.643
75	27.38	35.68	23.13	0.358	1.524
100	27.36	35.68	23.14	0.478	1.404
150	27.03	35.72	23.27	0.716	1.166
200	22.26	36.06	24.97	0.910	0.972
250	14.50	35.14	26.21	1.035	0.847
300	10.90	34.83	26.68	1.119	0.763
400	09.18	34.68	26.86	1.256	0.626
500	08.06	34.61	26.98	1.379	0.503
600	07.06	34.56	27.08	1.492	0.390
700	06.34	34.54	27.17	1.597	0.285
800	05.74	34.54	27.24	1.697	0.185
1000	04.81	34.53	27.35	1.882	0.000

STATION 75

M/V Hugh M. Smith: Cruise 8, 05°59'S, 168°29'W, February 16, 1951. Messenger time: 1225 GCT. Weather: broken clouds, no observation. Wind: 090°, 10 kt. Sea: 3-5 ft. Wire angle: 25°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.40	35.71	23.13	4.69	
09	27.50	35.70	23.10	4.70	
27	27.51	35.71	23.11	4.72	
54	27.45	35.69	23.11	4.82	
108	27.42	35.70	23.13	4.73	
202	24.23	36.07	24.41	3.74	
298	12.20	34.89	26.48	2.17	
392	09.37	34.70	26.84	2.46	
392	09.45	34.70	26.83		
492	07.54	34.57	27.03	2.92	
591	06.60	34.51	27.11	3.01	
800	05.25	34.49	27.26	2.76	
1005	04.31	34.52	27.39	2.42	
1005	04.25	34.52	27.40		
1209	03.72	34.54	27.47	2.60	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.40	35.71	23.13	0.000	1.938
10	27.50	35.70	23.10	0.048	1.890
20	27.50	35.70	23.10	0.095	1.843
30	27.51	35.71	23.11	0.143	1.795
50	27.47	35.69	23.11	0.239	1.699
75	27.43	35.69	23.12	0.359	1.579
100	27.42	35.70	23.13	0.479	1.459
150	27.32	35.72	23.18	0.717	1.221
200	24.70	36.03	24.23	0.931	1.007
250	19.18	35.65	25.49	1.090	0.848
300	12.02	34.88	26.51	1.195	0.743
400	09.21	34.69	26.86	1.339	0.599
500	07.45	34.57	27.04	1.459	0.479
600	06.51	34.50	27.11	1.567	0.371
700	05.88	34.50	27.19	1.668	0.270
800	05.25	34.49	27.26	1.762	0.176
1000	04.31	34.52	27.39	1.938	0.000

STATION 76

M/V Hugh M. Smith: Cruise 8, 07°04'S, 168°48'W, February 16, 1951. Messenger time: 2050 GCT. Weather: scattered clouds, cumulus. Wind: 060°, 9 kt. Sea: 3-5 ft. Wire angle: 16°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	27.61	35.63	23.02	4.69	
14	27.56	35.65	23.05	4.76	
28	27.55	35.65	23.05	4.69	
57	27.52	35.66	23.07	4.67	
109	27.43	35.64	23.08	4.67	
210	24.04	36.13	24.51	3.56	
312	14.62	35.08	26.14	2.72	
420	09.16	34.65	26.34	2.44	
420	09.22	34.65	26.33		
520	07.70	34.58	27.01	2.89	
622	06.44	34.51	27.13	2.81	
826	05.06	34.49	27.29	2.56	
1029	04.30	34.51	27.39	2.72	
1232	03.62	34.54	27.48	2.88	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(27.60)	(35.63)	23.02	0.000	2.007
10	27.59	35.64	23.03	0.049	1.958
20	27.55	35.65	23.05	0.097	1.910
30	27.55	35.65	23.05	0.145	1.862
50	27.54	35.66	23.06	0.242	1.765
75	27.47	35.65	23.05	0.363	1.644
100	27.45	35.64	23.08	0.484	1.523
150	26.40	35.79	23.52	0.717	1.290
200	25.30	35.98	24.01	0.929	1.078
250	20.33	35.81	25.30	1.099	0.908
300	15.83	35.20	25.96	1.223	0.784
400	09.63	34.69	26.79	1.399	0.608
500	08.01	34.60	26.98	1.526	0.481
600	06.72	34.53	27.11	1.638	0.369
700	05.76	34.50	27.21	1.740	0.267
800	05.18	34.49	27.27	1.833	0.174
1000	04.42	34.50	27.37	2.007	0.000

STATION 77

M/V *Hugh M. Smith*: Cruise 8, 13°30'S, 171°51'W, February 27, 1951. Messenger time: 0555 GCT. Weather: overcast (with breaks), cumulus and cirrus. Wind: 080°, 12 kt. Sea: 5-8 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
05	29.13	35.04	22.07	4.54	0.40
15	29.07	35.03	22.09	4.56	0.42
29	28.96	35.06	22.14	4.57	0.44
58	28.77	35.16	22.28	4.51	0.42
112	27.26	35.56	23.08	4.65	0.55
215	21.64	35.92	25.03	3.75	0.56
316	15.96	35.28	25.99	3.36	1.01
316	15.90	35.28	26.00		
423	10.01	34.64	26.69	2.85	1.78
528	07.50	34.52	26.99	3.16	2.06
631	06.18	34.48	27.14	3.41	2.26
834	04.91	34.49	27.30	3.19	2.21
1041	04.10	34.50	27.40	3.36	2.44
1244	03.46	34.53	27.49	3.18	2.60

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(29.10)	(35.04)	22.84	0.000	2.061
10	29.09	35.04	22.08	0.058	2.003
20	28.98	35.04	22.12	0.115	1.946
30	28.93	35.06	22.15	0.172	1.889
50	28.82	35.13	22.24	0.285	1.776
75	28.14	35.34	22.63	0.421	1.640
100	27.30	35.55	23.06	0.548	1.513
150	26.02	35.80	23.65	0.779	1.282
200	23.02	36.03	24.73	0.970	1.091
250	20.15	35.77	25.33	1.122	0.939
300	16.90	35.40	25.86	1.248	0.813
400	11.08	34.73	26.57	1.439	0.622
500	08.05	34.54	26.93	1.580	0.481
600	06.51	34.49	27.10	1.694	0.367
700	05.65	34.48	27.21	1.796	0.265
800	05.08	34.48	27.28	1.889	0.172
1000	04.28	34.49	27.37	2.061	0.000

STATION 78

M/V Hugh M. Smith: Cruise 8, 11°55'S, 171°59'W, February 27, 1951. Messenger time: 2200 GCT. Weather: broken clouds, cumulus, stratocumulus, altocumulus and cirrus. Wind: 080°, 7 kt. Sea: 1-3 ft. Wire angle: 19°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/1)	O2 (ml/1)	PO4-P (μg at/1)
04	28.89	35.00	22.12	4.57	0.32
13	28.82	35.05	22.18	4.54	0.50
13					0.26
27	28.83	35.05	22.18	4.54	0.25
50	28.82	35.07	22.20	4.49	0.30
97	28.10	35.68	22.89	4.60	0.35
187	22.84	36.06	24.80	3.68	0.58
272	17.92	35.53	25.71	3.66	0.83
364	12.94	34.89	26.34	3.25	1.49
455	09.04	34.60	26.82	2.85	2.15
550	07.33	34.52	27.02	3.19	2.27
738	05.57	34.46	27.20	3.37	2.43
924	04.56	34.51	27.36	3.23	2.58
1123	03.94	34.51	27.42	3.11	2.65

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/1)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	(28.90)	(35.00)	22.12	0.000	2.029
10	28.83	35.05	22.18	0.057	1.972
20	28.82	35.05	22.18	0.114	1.915
30	28.83	35.05	22.18	0.170	1.859
50	28.82	35.07	22.20	0.284	1.745
75	28.67	35.21	22.35	0.423	1.606
100	27.92	35.76	23.01	0.554	1.475
150	25.88	36.02	23.86	0.779	1.250
200	22.10	35.98	24.95	0.959	1.070
250	19.00	35.64	25.53	1.100	0.929
300	16.45	35.35	25.93	1.218	0.811
400	11.15	34.72	26.55	1.407	0.622
500	08.10	34.56	26.93	1.547	0.482
600	06.72	34.49	27.08	1.662	0.367
700	05.80	34.47	27.18	1.765	0.264
800	05.15	34.48	27.27	1.860	0.169
1000	04.25	34.52	27.40	2.029	0.000

STATION 79

M/V Hugh M. Smith: Cruise 8, 09°51'S, 171°51'W, February 28, 1951. Messenger time: 1310 GCT. Weather: overcast (with breaks), cumulus and altocumulus. Wind: 090°, 9 kt. Sea: 1-3 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	28.59	35.36	22.49	4.59	0.37
14	28.54	35.36	22.51	4.61	0.37
29	28.60	35.44	22.55	4.59	0.34
52	28.61	35.51	22.60	4.56	0.33
102	28.42	35.58	22.71	4.60	0.44
203	24.58	36.00	24.24	3.21	0.73
296	17.32	35.45	25.80	3.38	0.95
395	10.40	34.71	26.67	2.48	1.97
490	07.97	34.60	26.98	2.76	2.01
592	06.80	34.56	27.12	2.82	2.36
788	05.40	34.50	27.25	2.84	2.44
982	04.46	34.51	27.37	2.85	2.60
1188	03.64	34.56	27.49	2.91	2.57

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	(28.60)	(35.36)	22.49	0.000	2.090
10	28.55	35.36	22.51	0.054	2.036
20	28.54	35.40	22.54	0.107	1.983
30	28.60	35.44	22.55	0.160	1.930
50	28.61	35.51	22.60	0.266	1.824
75	28.60	35.54	22.62	0.398	1.692
100	28.45	35.57	22.70	0.529	1.561
150	27.77	35.71	23.02	0.782	1.308
200	24.90	35.99	24.14	1.001	1.089
250	20.92	35.85	25.18	1.170	0.920
300	17.15	35.42	25.82	1.299	0.791
400	10.15	34.70	26.71	1.485	0.605
500	07.81	34.59	27.00	1.614	0.476
600	06.74	34.56	27.13	1.723	0.367
700	06.00	34.52	27.19	1.824	0.266
800	05.32	34.50	27.26	1.918	0.172
1000	04.39	34.52	27.39	2.090	0.000

STATION 80

M/V Hugh M. Smith: Cruise 8, 08°00'S, 171°56'W, March 1, 1951. Messenger time: 0438 GCT. Weather: scattered clouds, cumulus. Wind: 040°, 15 kt. Sea: 3-5 ft. Wire angle: 27°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	28.68	35.40	22.49	4.54	0.37
12	28.68	35.43	22.51	4.54	0.36
25	28.34	35.51	22.69	4.55	0.37
51	28.23	35.73 1/	22.89 1/	4.53	0.52
96	28.12	35.62	22.84	4.56	0.54
181	25.79	35.97	23.85	3.41	0.75
267 2/	16.21	35.71	26.26	4.03	0.60
359	11.40	34.83	26.59	2.36	2.06
447	08.56	34.67	26.95	2.99	2.22
538	07.50	34.59	27.05	2.83	2.41
715	05.90	34.51	27.20	2.95	2.53
899	04.90	34.51	27.32	2.93	2.68
1089	04.19	34.53	27.41	2.87	2.76

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	(28.70)	(35.40)	22.49	0.000	1.997
10	28.69	35.42	22.50	0.054	1.943
20	28.40	35.49	22.65	0.106	1.891
30	28.31	35.52	22.69	0.158	1.839
50	28.25	35.54	22.74	0.262	1.735
75	28.19	35.60	22.80	0.390	1.607
100	28.12	35.62	22.84	0.517	1.480
150	27.80	35.69	23.00	0.767	1.230
200	24.10	36.05	24.43	0.980	1.017
250	17.95	35.56	25.73	1.129	0.868
300	14.20	35.11	26.25	1.234	0.763
400	09.75	34.72	26.80	1.395	0.602
500	07.90	34.62	27.01	1.519	0.478
600	06.82	34.56	27.12	1.629	0.368
700	06.00	34.52	27.19	1.730	0.267
800	05.40	34.51	27.26	1.824	0.173
1000	04.48	34.52	27.38	1.997	0.000

1/ Anomalous values.

2/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 81

M/V *Hugh M. Smith*: Cruise 8, 07°01'S, 171°54'W, March 1, 1951. Messenger time: 1304 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 030°, 14 kt. Sea: 3-5 ft. Wire angle: no observation

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.50	35.38	22.54	4.59	0.38
10	28.48	35.39	22.55	4.61	0.38
26	28.50	35.41	22.56	4.60	0.48
54	28.18	35.57	22.78	4.54	0.49
107	28.04	35.65	22.89	4.57	0.61
208	23.27	36.12	24.72	3.54	0.77
314	13.04	35.01	26.41	2.47	1.75
420	09.44	34.70	26.83	2.36	2.25
523	07.79	34.57	26.99	2.61	2.30
629	06.62	34.52	27.11	2.87	2.28
834	05.14	34.50	27.29	2.70	2.53
1038	04.30	34.52	27.39	2.79	2.61
1241	03.48	34.55	27.50	2.85	2.58

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	28.50	35.38	22.54	0.000	2.016
10	28.48	35.39	22.55	0.053	1.963
20	28.50	35.40	22.55	0.106	1.910
30	28.50	35.42	22.57	0.159	1.857
50	28.18	35.57	22.79	0.263	1.753
75	28.09	35.61	22.84	0.390	1.626
100	28.05	35.62	22.87	0.516	1.500
150	27.37	35.80	23.22	0.761	1.255
200	24.62	36.10	24.31	0.974	1.042
250	19.25	35.73	25.53	1.131	0.885
300	14.02	35.12	26.29	1.241	0.775
400	09.90	34.74	26.79	1.401	0.615
500	08.09	34.59	26.96	1.529	0.487
600	06.91	34.53	27.08	1.643	0.373
700	06.01	34.51	27.19	1.747	0.269
800	05.29	34.50	27.27	1.842	0.174
1000	04.48	34.52	27.38	2.016	0.000

STATION 82

M/V Hugh M. Smith: Cruise 8, 05°59'S, 172°00'W, March 1, 1951. Messenger time: 2147 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 050°, 16 kt. Sea: 3-5 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.20	35.67	22.85	4.57	0.47
08	28.22	35.66	22.84	4.60	0.48
21	28.22	35.67	22.85	4.58	0.43
45	28.08	35.71	22.92	4.53	0.50
86	27.84	35.68	22.98	4.58	0.57
161	25.68	36.06	23.95	3.71	0.74
236 1/	19.16	35.87	25.66	3.65	0.77
313	12.48	34.93	26.46	2.35	1.91
390	09.58	34.73	26.83	2.46	2.21
469	07.92	34.62	27.01	2.72	2.37
630	06.34	34.52	27.15	2.94	2.48
798	05.29	34.51	27.28	2.81	2.63
984	04.56	34.51	27.36		

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.20	35.67	22.85	0.000	1.919
10	28.22	35.66	22.84	0.050	1.869
20	28.20	35.67	22.85	0.100	1.819
30	28.21	35.68	22.86	0.151	1.768
50	28.02	35.71	22.94	0.250	1.669
75	27.90	35.68	22.96	0.374	1.545
100	27.63	35.70	23.06	0.497	1.422
150	26.88	35.85	23.42	0.731	1.188
200	23.70	36.13	24.61	0.930	0.989
250	18.15	35.60	25.71	1.075	0.844
300	13.22	35.02	26.38	1.178	0.741
400	09.31	34.71	26.86	1.329	0.590
500	07.50	34.58	27.04	1.448	0.471
600	06.52	34.53	27.14	1.555	0.364
700	05.81	34.51	27.21	1.655	0.264
800	05.28	34.51	27.28	1.747	0.172
1000	(04.49)	(34.52)	27.37	1.919	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 83

M/V Hugh M. Smith: Cruise 8, 05°00'S, 172°16'W, March 2, 1951. Messenger time: 0558 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 050°, 12 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.70	35.70	23.02	4.69	0.66
08	27.75	35.69	23.02	4.69	0.57
25	27.68	35.72	23.06	4.69	0.53
50	27.63	35.70	23.06	4.64	0.57
99	27.45	35.70	23.12	4.69	0.64
187	23.86			3.67	
276 1/	13.22	35.48	26.74	3.28	0.53
365	09.74	34.75	26.82	1.87	2.30
459	08.66	34.67	26.93	1.83	2.47
550	07.66	34.66	27.08	1.77	2.44
744	05.90	34.52	27.21	2.42	2.48
931	04.92	34.52	27.33	2.55	2.63
1125	04.16	34.54	27.43	2.47	2.60

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.70	35.70	23.02	0.000	1.871
10	27.73	35.70	23.03	0.049	1.822
20	27.70	35.71	23.05	0.097	1.774
30	27.67	35.70	23.05	0.145	1.726
50	27.63	35.70	23.06	0.242	1.629
75	27.55	35.70	23.09	0.363	1.508
100	27.45	35.70	23.12	0.484	1.387
150	26.30	35.89	23.63	0.713	1.158
200	22.08	35.93	24.96	0.903	0.968
250	14.90	35.21	26.17	1.032	0.839
300	11.83	34.90	26.56	1.119	0.752
400	09.23	34.71	26.87	1.262	0.609
500	08.19	34.66	27.00	1.383	0.488
600	07.14	34.62	27.12	1.494	0.377
700	06.29	34.54	27.17	1.597	0.274
800	05.55	34.52	27.25	1.694	0.177
1000	04.63	34.54	27.37	1.871	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 84

M/V *Hugh M. Smith*: Cruise 8, 04°00'S, 172°06'W, March 2, 1951. Messenger time: 1800 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 040°, 10 kt. Sea: 3-5 ft. Wire angle: 19°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.20	35.60	23.13	4.68	0.77
10	27.27	35.61	23.11	4.67	0.62
24	27.27	35.61	23.11	4.68	0.58
52	27.25	35.61	23.12	4.63	0.64
102	27.10	35.56	23.13	4.67	0.67
198	22.64	34.28 1/	23.51 1/	3.58	0.76
295 2/	11.53	35.15	26.81	2.19	1.60
396	09.12	34.69	26.88	2.18	2.35
492	08.30	34.63	26.96	1.93	2.50
589	07.20	34.56	27.07	1.85	2.68
779	05.70	34.51	27.22	2.03	2.77
974	04.62	34.52	27.36	2.22	2.83
1170	03.88	34.54	27.45	2.41	2.83

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	27.20	35.60	23.13	0.000	1.861
10	27.27	35.61	23.11	0.048	1.813
20	27.27	35.61	23.11	0.095	1.766
30	27.26	35.61	23.11	0.143	1.718
50	27.25	35.61	23.12	0.239	1.622
75	27.20	35.58	23.11	0.358	1.503
100	27.09	35.56	23.13	0.478	1.383
150	26.81	35.63	23.27	0.715	1.146
200	22.10	35.93	24.92	0.910	0.951
250	13.06	35.03	26.42	1.030	0.831
300	11.38	34.87	26.62	1.109	0.752
400	09.10	34.69	26.88	1.247	0.614
500	08.21	34.62	26.96	1.370	0.491
600	07.10	34.56	27.08	1.484	0.377
700	06.29	34.52	27.16	1.589	0.272
800	05.58	34.51	27.24	1.687	0.174
1000	04.49	34.53	27.38	1.861	0.000

1/ Anomalous values.

2/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 85

M/V Hugh M. Smith: Cruise 8, 03°00'S, 171°50'W, March 3, 1951. Messenger time: 0210 GCT. Weather: broken clouds, cumulus. Wind: 060°, 14 kt. Sea: 3-5 ft. Wire angle: 35°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O$_2$ (ml/l)	PO$_4$-P (µg at/l)
00	27.20	35.51	23.06	4.73	0.68
09	27.12	35.49	23.07	4.76	0.66
21	26.98	35.50	23.12	4.75	0.62
46	26.93	35.50	23.14	4.73	0.66
89	26.81	35.50	23.18	4.76	0.67
163	25.16	35.91	24.00	3.90	0.73
236[1/]	12.54	35.40	26.81	3.30	1.01
318	10.02	34.76	26.78	2.53	1.98
401	09.10	34.68	26.87	2.41	2.21
484	08.47	34.61	26.92	1.99	2.35
655	06.94	34.55	27.09	1.92	2.57
835	05.28	34.50	27.27	2.07	2.72
1024	04.35	34.55	27.41	2.27	2.76

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.20	35.51	23.06	0.000	1.821
10	27.10	35.49	23.08	0.048	1.773
20	26.99	35.50	23.12	0.096	1.725
30	26.97	35.50	23.13	0.144	1.677
50	26.92	35.50	23.14	0.239	1.582
75	26.88	35.50	23.15	0.358	1.463
100	26.80	35.51	23.19	0.477	1.344
150	26.42	35.59	23.37	0.710	1.111
200	19.30	35.63	25.44	0.890	0.931
250	11.91	34.92	26.56	0.994	0.827
300	10.35	34.79	26.75	1.067	0.754
400	09.11	34.68	26.87	1.199	0.622
500	08.31	34.60	26.93	1.323	0.498
600	07.43	34.56	27.03	1.441	0.380
700	06.51	34.53	27.14	1.550	0.271
800	05.55	34.50	27.24	1.649	0.172
1000	04.42	34.55	27.41	1.821	0.000

[1/] Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 86

M/V Hugh M. Smith: Cruise 8, 02°00'S, 172°02'W, March 4, 1951. Messenger time: 0234 GCT. Weather: broken clouds, cumulus and cirrocumulus. Wind: 080°, 14 kt. Sea: 3-5 ft. Wire angle: 40°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.00	35.46	23.09	4.77	0.66
08	26.96	35.47	23.11	4.74	0.70
23	26.77	35.46	23.16	4.75	0.68
45	26.73	35.46	23.17	4.67	0.71
86	26.31	35.46	23.30	4.73	0.77
159	24.19	35.81	24.22	3.82	0.86
240 1/	12.90	35.14	26.54	2.64	1.62
319	10.26	34.75	26.73	2.00	2.26
408	09.69	34.70	26.79	1.82	2.40
493	08.86	34.66	26.89	1.65	2.57
676	06.56	34.55	27.15	2.12	2.77
858	04.91	34.53	27.34	2.30	2.90
1054	04.16	34.56	27.44	2.28	2.92

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.00	35.46	23.09	0.000	1.762
10	26.97	35.47	23.10	0.048	1.714
20	26.79	35.47	23.16	0.095	1.667
30	26.76	35.46	23.16	0.143	1.619
50	26.71	35.46	23.18	0.237	1.525
75	26.64	35.46	23.20	0.355	1.407
100	26.20	35.47	23.35	0.471	1.291
150	24.90	35.79	23.99	0.686	1.076
200	16.22	35.29	25.94	0.839	0.923
250	12.25	34.93	26.51	0.932	0.830
300	10.48	34.78	26.72	1.008	0.754
400	09.77	34.70	26.78	1.146	0.616
500	08.79	34.65	26.90	1.277	0.485
600	07.51	34.60	27.05	1.396	0.366
700	06.29	34.55	27.18	1.501	0.261
800	05.38	34.53	27.28	1.596	0.166
1000	04.29	34.56	27.43	1.762	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 87

M/V Hugh M. Smith: Cruise 8, 00°57'S, 172°00'W, March 4, 1951. Messenger time: 1105 GCT. Weather: broken clouds, no observation. Wind: 080°, 12 kt. Sea: 3-5 ft. Wire angle: 47°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.30	35.39	23.25	4.73	0.68
10	26.30	35.38	23.25	4.75	0.68
21	26.20				
47	26.10	35.38	23.31	4.67	0.68
93	25.82	35.38	23.40	4.75	0.67
180	19.67	35.64	25.35	3.16	1.07
280 1/	11.67	35.07	26.72	3.03	1.52
389	10.06	34.74	26.76	1.80	2.31
494	08.47	34.62	26.92	2.04	2.51
609	06.74	34.52	27.10	1.83	2.75
831	05.18	34.51	27.29	2.34	2.70
1059	04.21	34.53	27.41	2.27	2.78
1339	03.21	34.56	27.53	2.31	2.80

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	35.39	23.25	0.000	1.767
10	26.30	35.38	23.25	0.046	1.721
20	26.21	35.38	23.28	0.093	1.674
30	26.16	35.38	23.29	0.139	1.629
50	26.09	35.38	23.31	0.231	1.536
75	25.91	35.38	23.37	0.345	1.422
100	25.80	35.38	23.40	0.459	1.308
150	25.22	35.53	23.70	0.679	1.088
200	15.82	35.27	26.01	0.837	0.930
250	13.35	35.04	26.37	0.932	0.835
300	11.25	34.85	26.63	1.012	0.755
400	09.87	34.72	26.78	1.155	0.612
500	08.40	34.61	26.93	1.285	0.482
600	06.86	34.53	27.09	1.400	0.367
700	05.92	34.51	27.20	1.502	0.265
800	05.30	34.51	27.27	1.596	0.171
1000	04.46	34.52	27.38	1.767	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 88

M/V Hugh M. Smith: Cruise 8, 00°09'N, 171°58'W, March 4, 1951. Messenger time: 1950 GCT. Weather: scattered clouds, cumulus. Wind: 140°, 8 kt. Sea: 3-5 ft. Wire angle: 52°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.00	35.34	23.31	4.69	0.68
10	26.06	35.37	23.31	4.74	0.77
22	26.02				
44	25.95	35.34	23.32	4.61	0.78
83	25.68	35.37	23.43		
159	22.40	35.24	24.31	3.53	1.01
246	14.17	35.06	26.22	3.34	1.37
345	10.97	34.82	26.66	2.42	2.08
441	08.82	34.71	26.94	1.52	2.50
552	07.52	34.62	27.07	1.95	2.63
773	05.52	34.55	27.28	2.03	2.85
1004	04.32	34.58	27.44	2.14	2.92
1268	03.46	34.59	27.54	2.19	2.92

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.00	35.34	23.31	0.000	1.744
10	26.06	35.37	23.31	0.046	1.698
20	26.02	35.36	23.32	0.092	1.652
30	26.00	35.34	23.31	0.137	1.607
50	25.92	35.34	23.34	0.229	1.515
75	25.73	35.37	23.42	0.342	1.402
100	25.50	35.37	23.49	0.454	1.290
150	23.30	35.32	24.11	0.662	1.082
200	16.39	35.16	25.30	0.816	0.928
250	14.05	35.03	26.22	0.920	0.824
300	12.38	34.91	26.46	1.008	0.736
400	09.61	34.74	26.83	1.156	0.588
500	08.12	34.66	27.01	1.279	0.465
600	07.01	34.58	27.11	1.389	0.355
700	06.09	34.56	27.21	1.490	0.254
800	05.37	34.56	27.30	1.581	0.163
1000	04.37	34.58	27.43	1.744	0.000

STATION 89

M/V *Hugh M. Smith*: Cruise 8, 01°04'N, 172°00'W, March 5, 1951. Messenger time: 0323 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 040°, 9 kt. Sea: 3-5 ft. Wire angle: 60°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.70	35.24	23.02	4.81	0.62
09	26.20	35.25	23.18	4.83	0.66
18	26.10				
38	25.95	35.26	23.26	4.80	0.61
67	25.88				
112	25.77	35.30	23.35	4.61	0.66
149	22.00	35.24	24.42	4.81	0.67
191	14.00	34.72	25.99	3.14	1.41
238	12.34	34.67	26.29	3.00	1.62
302	11.07	34.78	26.61	2.54	1.86
427	09.45	34.70	26.83	1.56	2.31
544	07.65	34.59	27.02	1.63	2.61
704	06.25	34.54	27.18	1.86	2.62

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.70	35.24	23.02		
10	26.20	35.25	23.18		
20	26.07	35.25	23.22		
30	26.00	35.26	23.25		
50	25.91	35.27	23.29		
75	25.86	35.27	23.30		
100	25.80	35.29	23.34		
150	21.50	35.21	24.54		
200	13.52	34.69	26.07		
250	12.02	34.69	26.36		
300	11.10	34.78	26.61		
400	09.85	34.72	26.78		
500	08.25	34.62	26.96		
600	07.09	34.56	27.08		
700	06.24	34.54	27.18		

STATION 90

M/V *Hugh M. Smith*: Cruise 8, 01°54'N, 172°02'W, March 5, 1951. Messenger time: 1050 GCT. Weather: moderate intermittent rain, no observation. Wind: 080°, 10 kt. Sea: 3-5 ft. Wire angle: 36°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.40	35.22	23.10	4.86	0.67
12	26.34	35.22	23.11	4.86	0.68
28	26.22	35.21	23.14	4.84	0.61
59	26.13	35.25	23.20	4.78	0.70
118	26.00	35.22	23.22	4.63	0.76
226	11.97	34.80	26.46	2.95	1.71
329	10.38	34.75	26.71	1.77	2.27
448	09.66	34.70	26.80	1.60	2.41
561	07.76	34.59	27.01	2.08	2.53
685	06.60	34.53	27.12	1.66	2.81
934	04.59	34.53	27.37	2.06	2.90
1200	03.58	34.56	27.50	2.20	2.96
1469	02.96	34.61	27.60	2.40	2.90

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.40	35.22	23.10	0.000	1.814
10	26.38	35.22	23.10	0.048	1.766
20	26.29	35.22	23.13	0.096	1.718
30	26.22	35.21	23.14	0.143	1.671
50	26.15	35.24	23.19	0.238	1.576
75	26.08	35.23	23.20	0.355	1.459
100	26.02	35.22	23.21	0.473	1.341
150	25.93	35.23	23.25	0.708	1.106
200	14.05	34.72	25.98	0.878	0.936
250	11.48	34.80	26.55	0.969	0.845
300	10.70	34.76	26.66	1.044	0.770
400	10.01	34.72	26.75	1.187	0.627
500	08.71	34.65	26.91	1.318	0.496
600	07.39	34.56	27.04	1.437	0.377
700	06.46	34.52	27.14	1.546	0.268
800	05.53	34.52	27.25	1.644	0.170
1000	04.31	34.54	27.41	1.814	0.000

STATION 91

M/V Hugh M. Smith: Cruise 8, 02°43'N, 172°04'W, March 5, 1951. Messenger time: 1858 GCT. Weather: broken clouds, cumulus, stratocumulus and cumulonimbus. Wind: 100°, 17 kt. Sea: 5-8 ft. Wire angle: 52°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.50	35.22	23.06	4.77	0.61
09	26.54	35.22	23.05	4.78	0.60
19	26.54	35.22	23.05	4.76	0.56
40	26.52	35.21	23.05	4.76	0.61
77	26.38	35.21	23.09	4.72	0.60
140	25.38	35.16	23.37	4.33	0.67
192 1/	12.03	35.19	26.75	4.64	0.76
251	10.64	34.74	26.65	2.51	1.97
311	10.26	34.74	26.72	1.69	2.28
382	09.70	34.70	26.79	1.57	2.44
541	08.09	34.61	26.98	1.91	2.50
736	06.00	34.56	27.23	1.46	2.82
957	04.53	34.53	27.38	1.95	2.88

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.50	35.22	23.06	0.000	1.756
10	26.53	35.21	23.05	0.048	1.708
20	26.53	35.21	23.05	0.097	1.659
30	26.52	35.21	23.05	0.145	1.611
50	26.45	35.21	23.07	0.242	1.514
75	26.38	35.21	23.09	0.362	1.394
100	26.24	35.21	23.14	0.482	1.274
150	24.21	35.13	23.70	0.708	1.048
200	11.70	34.75	26.47	0.855	0.901
250	10.66	34.75	26.66	0.932	0.824
300	10.36	34.74	26.71	1.003	0.753
400	09.52	34.68	26.80	1.141	0.615
500	08.51	34.63	26.93	1.269	0.487
600	07.45	34.59	27.05	1.386	0.370
700	06.38	34.57	27.19	1.492	0.264
800	05.50	34.55	27.28	1.586	0.170
1000	(04.40)	(34.53)	27.39	1.756	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 92

M/V Hugh M. Smith: Cruise 8, 03°57'N, 172°02'W, March 6, 1951. Messenger time: 0434 GCT. Weather: broken clouds, cumulus, altocumulus and cirrus. Wind: 070°, 16 kt. Sea: 5-8 ft. Wire angle: 42°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ t (g/1)	O_2 (ml/1)	PO_4-P (µg at/1)
00	27.20	35.13	22.77	4.72	0.50
12	27.15	35.10	22.77	4.77	0.49
27	27.02	35.10	22.81	4.68	0.48
56	26.88	35.15	22.89	4.66	0.58
109	26.59	35.21	23.03	4.68	0.68
205	16.99	34.71	25.31	2.84	1.29
303	09.21	34.65	26.83	1.75	2.39
416	08.23	34.60	26.95	2.00	2.47
416	08.29	34.60	26.94		
524	07.31	34.59	27.07	1.23	2.82
645	06.37	34.55	27.17	1.23	3.00
882	04.86	34.56	27.37	1.85	2.94
1127	03.89	34.53	27.45	2.06	2.94
1407	03.12	34.58	27.56	2.08	2.97

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/1)	Δ D (dyn. m)	Δ D 1000-Δ D (dyn. m)
00	27.20	35.13	22.77	0.000	1.823
10	27.15	35.10	22.77	0.051	1.772
20	27.09	35.10	22.79	0.102	1.721
30	27.00	35.10	22.81	0.153	1.670
50	26.90	35.13	22.87	0.253	1.570
75	26.75	35.17	22.95	0.378	1.445
100	26.62	35.19	23.00	0.502	1.321
150	26.40	35.21	23.09	0.746	1.077
200	18.50	34.81	25.02	0.942	0.881
250	10.41	34.72	26.68	1.053	0.770
300	09.26	34.65	26.82	1.121	0.702
400	08.39	34.60	26.92	1.247	0.576
500	07.51	34.59	27.04	1.363	0.460
600	06.71	34.57	27.14	1.469	0.354
700	05.98	34.56	27.23	1.568	0.255
800	05.30	34.56	27.31	1.658	0.165
1000	04.39	34.54	27.40	1.823	0.000

STATION 93

M/V *Hugh M. Smith*: Cruise 8, 04°56'N, 171°54'W, March 6, 1951. Messenger time: 1308 GCT. Weather: scattered clouds, no observation. Wind: 030°, 13 kt. Sea: 5-8 ft. Wire angle: < 3°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO4-P (µg at/l)
05	27.07	35.09	22.78	4.67	0.57
20	27.08	35.08	22.77	4.70	0.43
41	27.10	35.08	22.77	4.69	0.45
80	27.00	35.08	22.80	4.69	0.55
154	26.42	35.20	23.07	4.55	0.61
301	09.66	34.67	26.77	1.00	2.35
440	08.17	34.59	26.95	1.11	2.64
584	06.92	34.58	27.12	0.98	2.62
584	06.98	34.58	27.11		
731	05.53	34.53	27.26	1.40	2.88
883	04.74	34.52	27.35	1.57	2.75
1175	03.76	34.56	27.48	1.92	2.74
1469	03.08	34.59	27.57	2.06	2.72
1767	02.54	34.60	27.63	2.15	2.65

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	ΔD1000-ΔD (dyn. m)
00	27.10	35.09	22.78	0.000	1.830
10	27.09	35.08	22.77	0.051	1.779
20	27.08	35.08	22.77	0.102	1.728
30	27.09	35.08	22.77	0.153	1.677
50	27.08	35.08	22.77	0.255	1.575
75	27.01	35.08	22.80	0.383	1.447
100	26.98	35.11	22.83	0.510	1.320
150	26.53	35.19	23.03	0.760	1.070
200	16.20	34.66	25.46	0.947	0.883
250	10.60	34.68	26.62	1.049	0.781
300	09.70	34.67	26.76	1.120	0.710
400	08.52	34.60	26.90	1.249	0.581
500	07.67	34.58	27.01	1.368	0.462
600	06.79	34.58	27.14	1.476	0.354
700	05.80	34.54	27.24	1.574	0.256
800	05.12	34.52	27.30	1.665	0.165
1000	04.26	34.53	27.41	1.830	0.000

STATION 94

M/V *Hugh M. Smith*: Cruise 8, 05°55'N, 171°50'W, March 6, 1951. Messenger time: 2135 GCT. Weather: broken clouds, cumulus, stratocumulus and altocumulus. Wind: 010°, 15 kt. Sea: 5-8 ft. Wire angle: 16°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
08	27.26	35.01	22.66	4.67	0.45
17	27.26	35.00	22.66	4.69	0.46
30	27.26	34.99	22.65	4.66	0.39
61	27.26	35.01	22.66	4.62	0.47
113	27.10	35.08	22.77	4.63	0.48
210	11.17	34.54	26.41	1.17	2.30
308	09.42	34.65	26.80	1.06	2.53
412	08.45	34.63	26.93	1.15	2.63
412	08.51	34.63	26.92		
513	07.41	34.57	27.04	0.90	2.89
614	06.60	34.55	27.14	0.97	2.97
813	05.32	34.52	27.28	1.27	2.95
1014	04.41	34.53	27.39	1.52	2.97
1217	03.71	34.54	27.47	1.84	2.95

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(27.30)	(34.99)	22.64	0.000	1.747
10	27.26	34.99	22.65	0.052	1.695
20	27.26	34.99	22.65	0.104	1.643
30	27.26	34.99	22.65	0.157	1.590
50	27.26	35.00	22.66	0.261	1.486
75	27.25	35.01	22.67	0.392	1.355
100	27.22	35.02	22.68	0.522	1.225
150	21.40	34.97	24.38	0.743	1.004
200	11.90	34.47	26.22	0.880	0.867
250	10.20	34.64	26.66	0.962	0.785
300	09.52	34.65	26.78	1.032	0.715
400	08.53	34.63	26.92	1.159	0.588
500	07.58	34.57	27.02	1.277	0.470
600	06.60	34.55	27.14	1.385	0.362
700	05.90	34.54	27.22	1.483	0.264
800	05.39	34.52	27.27	1.576	0.171
1000	04.48	34.53	27.38	1.747	0.000

STATION 95

M/V Hugh M. Smith: Cruise 8, 06°58'N, 171°49'W, March 7, 1951. Messenger time: 0608 GCT. Weather: broken clouds, cumulus, altocumulus and cirrus. Wind: 020°, 17 kt. Sea: 5-8 ft. Wire angle: 23°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.30	34.58	22.33	4.70	0.26
10	27.36	34.60	22.32	4.71	0.28
24	27.36	34.58	22.31	4.73	0.23
52	27.25	34.59	22.35	4.70	0.27
104	27.23	34.60	22.37	4.71	0.28
192	11.39	34.45	26.30	1.81	1.98
287	09.75	34.65	26.74	0.78	2.62
390	08.81	34.63	26.88	1.23	2.50
390	08.87	34.63	26.87		
488	08.12	34.59	26.96	1.14	2.54
588	07.18	34.55	27.06	0.92	2.82
780	05.80	34.53	27.23	1.19	2.82
978	04.72	34.54	27.36	1.62	2.83
1179	03.91	34.56	27.47	1.82	2.78

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.30	34.58	22.33	0.000	1.763
10	27.36	34.60	22.32	0.055	1.708
20	27.36	34.57	22.30	0.111	1.652
30	27.33	34.57	22.31	0.166	1.597
50	27.22	34.59	22.36	0.277	1.486
75	27.22	34.59	22.36	0.414	1.349
100	27.21	34.60	22.37	0.552	1.211
150	17.18	34.63	25.21	0.761	1.002
200	11.11	34.54	26.42	0.873	0.890
250	10.20	34.65	26.66	0.950	0.813
300	09.63	34.65	26.76	1.020	0.743
400	08.78	34.63	26.88	1.151	0.612
500	08.00	34.58	26.96	1.273	0.490
600	07.05	34.55	27.08	1.387	0.376
700	06.31	34.54	27.17	1.491	0.272
800	05.69	34.53	27.24	1.588	0.175
1000	04.59	34.55	27.39	1.763	0.000

STATION 96

M/V *Hugh M. Smith*: Cruise 8, 07°56'N, 171°51'W, March 7, 1951. Messenger time: 1434 GCT. Weather: scattered clouds, no observation. Wind: 060°, 15 kt. Sea: 3-5 ft. Wire angle: 24°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.10	34.51	22.34	4.74	0.25
11	27.15	34.50	22.32	4.74	0.23
24	27.16	34.48	22.30	4.66	0.22
52	27.15	34.48	22.30	4.65	0.26
104	23.52	34.79	23.65	4.81	0.33
202	10.97	34.57	26.47	0.95	2.40
298	09.60	34.64	26.76	0.61	2.60
401	08.78	34.60	26.86	0.92	2.69
499	07.56	34.53	26.99	0.75	2.81
599	06.68	34.50	27.09	0.90	2.89
791	05.26	34.48	27.25	1.37	2.91
987	04.30	34.51	27.39	1.62	2.88
1188	03.72	34.53	27.46	1.76	2.85

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.10	34.51	22.34	0.000	1.715
10	27.14	34.50	22.32	0.055	1.660
20	27.15	34.49	22.31	0.111	1.604
30	27.16	34.48	22.30	0.166	1.549
50	27.15	34.48	22.30	0.277	1.438
75	27.11	34.50	22.33	0.416	1.299
100	24.50	34.79	23.35	0.543	1.172
150	16.40	34.49	25.28	0.726	0.989
200	11.05	34.56	26.44	0.835	0.880
250	10.20	34.64	26.66	0.912	0.803
300	09.60	34.64	26.76	0.983	0.732
400	08.80	34.60	26.86	1.114	0.601
500	07.51	34.53	27.00	1.236	0.479
600	06.66	34.50	27.09	1.347	0.368
700	05.89	34.48	27.18	1.450	0.265
800	05.19	34.48	27.26	1.545	0.170
1000	04.25	34.51	27.39	1.715	0.000

STATION 97

M/V Hugh M. Smith: Cruise 8, 09°00'N, 171°58'W, March 7, 1951. Messenger time: 2346 GCT. Weather: scattered clouds, cumulus and cirrus. Wind: 020°, 14 kt. Sea: 3-5 ft. Wire angle: 24°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.80	34.35	22.31	4.74	0.22
09	26.73	34.34	22.33	4.74	0.22
23	26.72	34.34	22.33	4.75	0.20
50	26.71	34.35	22.35	4.72	0.22
100	21.74	34.78	24.14	4.81	0.34
202	11.34	34.52	26.36	1.24	2.07
301	09.82	34.65	26.73	0.56	2.53
404	08.82	34.62	26.87	0.65	2.51
504	07.88	34.57	26.97	0.74	2.62
604	06.80	34.52	27.09	0.84	2.80
801	05.36	34.55	27.30	0.97	2.89
1003	04.34	34.55	27.41	1.37	2.78
1204	03.70	34.55	27.48	1.66	2.76

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.80	34.35	22.31	0.000	1.680
10	26.72	34.34	22.33	0.055	1.625
20	26.72	34.34	22.33	0.110	1.570
30	26.72	34.34	22.33	0.166	1.514
50	26.71	34.35	22.34	0.276	1.404
75	26.69	34.36	22.36	0.414	1.266
100	21.74	34.78	24.14	0.531	1.149
150	15.60	34.46	25.44	0.691	0.989
200	11.40	34.51	26.34	0.799	0.881
250	10.50	34.64	26.60	0.880	0.800
300	09.88	34.66	26.73	0.953	0.727
400	08.89	34.63	26.87	1.086	0.594
500	07.91	34.57	26.97	1.208	0.472
600	06.82	34.52	27.09	1.321	0.359
700	06.01	34.54	27.21	1.423	0.257
800	05.39	34.55	27.29	1.515	0.165
1000	04.33	34.56	27.42	1.680	0.000

STATION 98

M/V *Hugh M. Smith*: Cruise 8, 10°02'N, 171°56'W, March 8, 1951. Messenger time: 0818 GCT. Weather: broken clouds, no observation. Wind: 010°, 14 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.30	34.33	22.46	4.80	0.18
09	26.36	34.31	22.42	4.87	0.22
22	26.34	34.30	22.42	4.83	0.37
49	26.26	34.29	22.44	4.79	0.25
96	22.95	34.87	23.87	5.03	0.33
184	11.87	34.37	26.14	2.48	1.76
275	09.46	34.57	26.73	0.80	2.54
374	08.73	34.59	26.86	1.06	2.61
468	08.06	34.55	26.93	1.01	2.68
565	07.26	34.55	27.05	1.09	2.74
757	05.68	34.52	27.23	1.11	2.93
955	04.69	34.53	27.36	1.49	2.87
1158	03.90	34.54	27.45	1.72	2.85

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.30	34.33	22.46	0.000	1.659
10	26.36	34.31	22.42	0.054	1.605
20	26.35	34.31	22.43	0.108	1.551
30	26.32	34.30	22.43	0.163	1.496
50	26.25	34.35	22.49	0.271	1.388
75	26.19	34.38	22.53	0.405	1.254
100	21.50	34.85	24.26	0.518	1.141
150	14.60	34.42	25.63	0.671	0.988
200	11.12	34.47	26.36	0.774	0.885
250	09.80	34.56	26.66	0.853	0.806
300	09.22	34.57	26.77	0.923	0.736
400	08.58	34.58	26.88	1.054	0.605
500	07.80	34.55	26.97	1.176	0.483
600	06.95	34.54	27.08	1.288	0.371
700	06.09	34.52	27.18	1.392	0.267
800	05.42	34.52	27.27	1.487	0.172
1000	04.49	34.53	27.38	1.659	0.000

STATION 99

M/V *Hugh M. Smith*: Cruise 8, 11°02'N, 171°52'W, March 8, 1951. Messenger time: 1633 GCT. Weather: no observation. Wind: 090°, 10 kt. Sea: 3-5 ft. Wire angle: 24°.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.10	34.35	22.53	4.78	0.20
09	26.15	34.35	22.52	4.80	0.19
22	26.14	34.38	22.54	4.81	0.15
48	26.15	34.36	22.53	4.80	0.19
97	23.56	34.96	23.76	5.08	0.19
193	12.13	34.40	26.12	2.48	1.58
287	09.72	34.54	26.66	0.67	2.38
385	08.48	34.55	26.87	0.65	2.47
480	07.65	34.55	26.99	0.83	2.46
579	06.80	34.52	27.09	0.73	2.52
774	05.48	34.51	27.25	0.87	2.68
972	04.46	34.53	27.39	1.24	2.68
1170		34.53		1.53	2.77

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.10	34.35	22.53	0.000	1.681
10	26.14	34.35	22.52	0.053	1.628
20	26.14	34.38	22.54	0.107	1.574
30	26.14	34.36	22.53	0.160	1.521
50	26.14	34.38	22.54	0.266	1.415
75	26.15	34.39	22.55	0.400	1.281
100	23.20	34.98	23.88	0.517	1.164
150	16.00	34.54	25.41	0.685	0.996
200	11.70	34.43	26.22	0.796	0.885
250	10.29	34.52	26.55	0.881	0.800
300	09.53	34.55	26.70	0.956	0.725
400	08.35	34.56	26.90	1.088	0.593
500	07.49	34.54	27.01	1.207	0.474
600	06.62	34.52	27.11	1.317	0.364
700	05.93	34.51	27.20	1.418	0.263
800	05.33	34.51	27.27	1.512	0.169
1000	04.35	34.53	27.40	1.681	0.000

STATION 100

M/V *Hugh M. Smith*: Cruise 8, 12°00'N, 171°52'W, March 9, 1951. Messenter time: 0048 GCT. Weather: broken clouds, altocumulus and cirrocumulus. Wind: 080°, 7 kt. Sea: 3-5 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	26.32	34.43	22.52	4.85	0.23
14	26.08	34.42	22.59	4.91	0.24
29	26.06	34.43	22.61	4.84	0.22
58	26.07	34.43	22.60	4.79	0.25
110	22.22	35.08	24.24	4.92	0.25
215	11.26	34.46	26.33	1.54	2.15
320	09.42	34.59	26.75	0.47	2.64
430	08.30	34.56	26.90	0.62	2.83
535	07.32	34.52	27.02	0.73	2.83
640	06.46	34.51	27.13	0.78	2.93
844	05.28	34.51	27.28	0.84	2.93
1051	04.31	34.56	27.42	1.26	2.93
1254	03.64	34.56	27.49	1.59	2.88

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(26.30)	(34.43)	22.53	0.000	1.733
10	26.13	34.42	22.58	0.053	1.680
20	26.07	34.42	22.60	0.106	1.627
30	26.06	34.43	22.61	0.158	1.575
50	26.07	34.43	22.60	0.264	1.469
75	26.00	34.45	22.64	0.395	1.338
100	24.90	34.74	23.20	0.520	1.213
150	18.68	34.82	24.98	0.714	1.019
200	11.90	34.43	26.18	0.837	0.896
250	10.48	34.53	26.52	0.924	0.809
300	09.65	34.58	26.70	0.998	0.735
400	08.00	34.57	26.96	1.128	0.605
500	07.65	34.53	26.98	1.245	0.488
600	06.80	34.51	27.08	1.358	0.375
700	06.13	34.51	27.17	1.462	0.271
800	05.53	34.51	27.25	1.559	0.174
1000	04.55	34.54	27.38	1.733	0.000

STATION 101

M/V *Hugh M. Smith*: Cruise 8, 13°01'N, 171°48'W, March 9, 1951. Messenger time: 0907 GCT. Weather: scattered clouds, no observation. Wind: 100°, 7 kt. Sea: 1-3 ft. Wire angle: 07°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
05	25.74	34.56	22.80	4.85	0.18
15	25.50	34.57	22.88	4.87	0.18
29	25.46	34.56	22.89	4.88	0.17
54	25.44	34.56	22.90	4.85	0.18
102	23.74	35.00	23.74	4.99	0.22
202	14.27	34.45	25.72	3.65	0.97
298	09.74	34.43	26.57	1.19	2.38
398	08.30	34.50	26.86	0.76	2.57
494	07.36	34.53	27.02	0.87	2.70
594	06.52	34.52	27.13	0.98	2.71
791	05.22	34.52	27.29	1.14	2.72
984	04.34	34.52	27.39	1.43	2.68
1191	03.66	34.58	27.51	1.57	2.70

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(25.70)	(34.56)	22.82	0.000	1.742
10	25.65	34.56	22.83	0.050	1.692
20	25.47	34.57	22.89	0.101	1.641
30	25.45	34.57	22.90	0.150	1.592
50	25.45	34.57	22.90	0.250	1.492
75	25.39	34.58	22.93	0.375	1.367
100	24.60	34.78	23.32	0.494	1.248
150	19.06	34.86	24.92	0.687	1.055
200	14.90	34.50	25.63	0.825	0.917
250	11.40	34.39	26.25	0.932	0.810
300	09.70	34.44	26.59	1.016	0.726
400	08.29	34.50	26.86	1.156	0.586
500	07.30	34.52	27.02	1.276	0.466
600	06.50	34.52	27.13	1.384	0.358
700	05.86	34.52	27.21	1.483	0.259
800	05.20	34.52	27.29	1.575	0.167
1000	04.30	34.53	27.40	1.742	0.000

STATION 102

M/V *Hugh M. Smith*: Cruise 8, 13°58'N, 171°24'W, March 9, 1951. Messenger time: 1720 GCT. Weather: broken clouds, cumulus and altocumulus. Wind: 080°, 9 kt. Sea: 3-5 ft. Wire angle: 10°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.30	34.53	22.92	4.83	0.25
10	25.30	34.54	22.92	4.83	0.23
25	25.32	34.52	22.90	4.89	0.22
50	25.28	34.54	22.93	4.85	0.26
100	23.02	35.09	24.02	4.91	0.22
198	14.95	34.51	25.62	4.03	0.86
292	09.68	34.25	26.44	2.51	2.06
390	07.91	34.34	26.79	1.19	2.57
482	07.08	34.43	26.98	0.90	2.72
581	06.18	34.45	27.12	0.89	2.87
774	05.10	34.50	27.29	1.01	2.97
965	04.36	34.52	27.39	1.29	2.90
1171	03.68	34.51	27.45	1.53	2.90

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.30	34.53	22.92	0.000	1.714
10	25.30	34.54	22.92	0.050	1.664
20	25.30	34.54	22.92	0.099	1.615
30	25.29	34.54	22.93	0.149	1.565
50	25.28	34.54	22.93	0.248	1.466
75	24.82	34.69	23.18	0.369	1.345
100	23.02	35.09	24.02	0.477	1.237
150	18.90	34.85	24.95	0.652	1.062
200	14.82	34.50	25.64	0.789	0.925
250	10.92	34.28	26.25	0.895	0.819
300	09.51	34.25	26.47	0.982	0.732
400	07.81	34.36	26.82	1.129	0.585
500	06.92	34.43	27.00	1.251	0.463
600	06.09	34.46	27.14	1.359	0.355
700	05.53	34.48	27.22	1.457	0.257
800	05.00	34.50	27.30	1.548	0.166
1000	04.26	34.52	27.40	1.714	0.000

STATION 103

M/V *Hugh M. Smith*: Cruise 8, 15°00'N, 170°52'W, March 10, 1951. Messenger time: 0228 GCT. Weather: dry haze, cumulus. Wind: 080°, 9 kt. Sea: 3-5 ft. Wire angle: 12°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.20	34.66	23.05	4.89	0.26
10	25.00	34.65	23.10	4.92	0.26
24	24.98	34.67	23.12	4.90	0.24
53	24.95	34.65	23.11	4.89	0.23
106	23.04	35.09	24.01	4.91	0.26
211	16.30	34.63	25.41	4.22	0.60
314	09.48	34.23	26.46	2.52	2.29
421	07.68	34.39	26.86	0.93	2.51
523	06.73	34.46	27.05	0.93	2.69
627	05.81	34.46	27.17	1.01	2.69
829	04.89	34.48	27.30	1.15	2.72
1036	04.00	34.54	27.44	1.35	2.76
1239	03.27	34.57	27.54	1.75	2.78

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.20	34.66	23.05	0.000	1.788
10	25.00	34.65	23.10	0.048	1.740
20	24.99	34.66	23.11	0.096	1.692
30	24.98	34.66	23.11	0.144	1.644
50	24.97	34.65	23.11	0.239	1.549
75	24.91	34.70	23.16	0.359	1.429
100	23.55	35.03	23.82	0.470	1.318
150	21.69	35.08	24.38	0.663	1.125
200	18.22	34.80	25.08	0.827	0.961
250	12.59	34.29	25.94	0.954	0.834
300	09.98	34.23	26.37	1.051	0.737
400	07.95	34.35	26.79	1.203	0.585
500	06.90	34.46	27.03	1.326	0.462
600	06.02	34.46	27.15	1.432	0.356
700	05.50	34.46	27.21	1.530	0.258
800	05.02	34.48	27.28	1.623	0.165
1000	04.15	34.53	27.42	1.788	0.000

STATION 104

M/V Hugh M. Smith: Cruise 8, 16°58'N, 169°41'W, March 10, 1951. Messenger time: 1905 GCT. Weather: broken clouds, cumulus, stratocumulus and altocumulus. Wind: 060°, 6 kt. Sea: 3-5 ft. Wire angle: 16°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	25.07	34.36	22.86	4.87	0.30
14	25.08	34.34	22.84	4.87	0.27
28	25.08	34.35	22.85	4.90	0.25
52	25.06	34.34	22.85	4.85	0.30
98	24.55	34.46	23.09	4.86	0.26
187	13.68	34.33	25.75	3.19	1.32
274 1/	10.46	34.35	26.39	1.23	2.21
364	07.76	34.22	26.72	1.69	2.51
451	06.62	34.27	26.92	1.14	2.68
546	05.91	34.34	27.06	1.01	2.88
732	05.12	34.48	27.27	1.06	2.88
909	04.30	34.51	27.39	1.30	2.87

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(25.10)	(34.36)	22.85	0.000	1.741
10	25.09	34.35	22.84	0.050	1.691
20	25.08	34.35	22.85	0.101	1.640
30	25.07	34.35	22.85	0.151	1.590
50	25.05	34.34	22.85	0.251	1.490
75	24.85	34.38	22.94	0.376	1.365
100	24.49	34.56	23.18	0.498	1.243
150	18.80	34.87	24.99	0.693	1.048
200	12.70	34.26	25.90	0.823	0.918
250	10.80	34.18	26.19	0.925	0.816
300	09.21	34.18	26.46	1.013	0.728
400	07.21	34.24	26.81	1.161	0.580
500	06.22	34.30	26.99	1.284	0.457
600	05.63	34.39	27.14	1.393	0.348
700	05.27	34.46	27.24	1.490	0.251
800	04.80	34.49	27.32	1.580	0.161
1000	(03.94)	(34.53)	27.44	1.741	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 105

M/V Hugh M. Smith: Cruise 8, 18°58'N, 168°27'W, March 11, 1951. Messenger time: 1230 GCT. Weather: scattered clouds, no observation. Wind: 260°, 7 kt. Sea: 1-3 ft. Wire angle: 09°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
05	24.56	34.65	23.23	4.87	0.20
15	24.51	34.63	23.23	4.92	0.17
30	24.50	34.67	23.26	4.93	0.18
54	24.21	34.96	23.57	4.93	0.17
102	23.43	35.21	23.99	4.94	0.18
195	17.85	34.79	25.17	4.42	0.43
284 1/	11.04	34.25	26.20	2.78	1.67
374	08.32	34.16	26.59	2.13	2.06
374	08.38	34.16	26.58		
466	07.08	34.24	26.83	1.25	2.46
559	06.01	34.27	27.00	1.08	2.69
742	04.99	34.43	27.25	1.24	2.74
925	04.38	34.49	27.36	1.30	2.50
1125	03.76	34.52	27.45	1.51	2.53

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	(24.60)	(34.65)	23.22	0.000	1.785
10	24.53	34.65	23.24	0.047	1.738
20	24.50	34.64	23.24	0.093	1.692
30	24.50	34.67	23.26	0.139	1.646
50	24.25	34.91	23.52	0.230	1.555
75	23.95	35.09	23.74	0.337	1.448
100	23.55	35.18	23.93	0.440	1.345
150	22.01	35.19	24.37	0.631	1.154
200	17.21	34.72	25.27	0.791	0.994
250	12.65	34.29	25.93	0.914	0.871
300	10.40	34.16	26.25	1.014	0.771
400	07.95	34.20	26.67	1.178	0.607
500	06.70	34.25	26.89	1.312	0.473
600	05.68	34.31	27.07	1.428	0.357
700	05.12	34.42	27.22	1.529	0.256
800	04.81	34.46	27.29	1.620	0.165
1000	04.15	34.51	27.40	1.785	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

STATION 106

M/V Hugh M. Smith: Cruise 8, 20°59'N, 167°07'W, March 12, 1951. Messenger time: 0540 GCT. Weather: broken clouds, cumulus and cirrus. Wind: 300°, 9 kt. Sea: 3-5 ft. Wire angle: 21°

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
05	23.64	35.20	23.92	5.02	0.12
14	23.64	35.21	23.93	5.05	0.12
28	23.48	35.20	23.97	5.03	0.12
28					0.08
51	23.43	35.20	23.98	5.01	0.08
97	23.03	35.28	24.16	5.00	0.12
190	17.73	34.85	25.24	4.35	0.38
280 1/	12.40	34.52	26.16	4.52	0.73
375	09.60	34.14	26.37	4.32	1.31
375	09.67	34.14	26.36		
465	07.64	34.05	26.60	3.16	1.93
559	06.05	34.10	26.86	1.94	2.40
743	04.84	34.33	27.18	1.13	2.75
928	04.20	34.49	27.38	1.36	2.77
1126	03.40	34.52	27.48	1.55	2.77

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	(23.70)	(35.20)	23.90	0.000	1.798
10	23.65	35.20	23.92	0.040	1.758
20	23.60	35.20	23.93	0.080	1.718
30	23.48	35.20	23.97	0.120	1.678
50	23.41	35.20	23.99	0.199	1.599
75	23.31	35.23	24.04	0.297	1.501
100	22.99	35.28	24.17	0.394	1.404
150	20.34	35.09	24.76	0.570	1.228
200	17.45	34.82	25.29	0.720	1.078
250	14.30	34.53	25.78	0.846	0.952
300	11.71	34.29	26.11	0.953	0.845
400	09.00	34.10	26.43	1.136	0.662
500	06.96	34.05	26.70	1.291	0.507
600	05.69	34.15	26.94	1.423	0.375
700	05.05	34.28	27.12	1.534	0.264
800	04.68	34.39	27.25	1.631	0.167
1000	03.92	34.51	27.43	1.798	0.000

1/ Point on T-S curve suggests bottle leaked on way up. Therefore all values at this level except temperature are probably in error.

MID-PACIFIC OCEANOGRAPHY III

TRANSEQUATORIAL WATERS

AUGUST - OCTOBER 1951

By

THOMAS S. AUSTIN

PACIFIC OCEANIC FISHERY INVESTIGATIONS

HONOLULU, T. H.

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MID-PACIFIC OCEANOGRAPHY III

Introduction

This is the third in a series of reports on oceanographic data collected by the Pacific Oceanic Fishery Investigations of the Fish and Wildlife Service. The first (Cromwell 1951) presented the oceanographic data from *Hugh M. Smith* cruise 2, the second (Cromwell 1954), the data from *Hugh M. Smith* cruises 5 and 8, and this report will be concerned with *Hugh M. Smith* cruise 11. The apparently missing numbers in the series of cruises by the *Smith* have been assigned to oceanographic cruises in the waters adjacent to the Hawaiian Islands or to fishery research cruises and will be the subject of other reports.

These reports, descriptive in nature, are being issued in order that the oceanographic data may, as quickly as is feasible, be made available to the other POFI investigations and to other organizations interested in the equatorial mid-Pacific area. It is anticipated that, once the series is complete and the data from all the cruises can be studied together, a series of more comprehensive, analytical reports will follow.

The objectives of the equatorial oceanographic cruises have been to describe, in as great detail as possible, the major currents and the distribution of physical and chemical properties of the waters of the mid-Pacific, to determine the spatial and temporal variations in these phenomena, and finally to provide physical and chemical oceanographic data to which can be related the distribution and abundance of marine organisms, especially tuna, near the Equator.

Description of Vessel, Equipment, and Procedures

The vessel, equipment, and procedures were described in some detail by Cromwell (1951, pp. 1-3). The only significant change, which we will describe below, is in the procedure for drawing the salinity curves and constructing the cross sections as modified from Montgomery (1954).

Some Results of Hugh M. Smith Cruise 11

Quoting from the cruise plan, the primary mission was "By means of (1) longline, (2) hydrographic, and (3) plankton stations, investigate the abundance of yellowfin tuna with respect to certain physical, chemical, and biological features of equatorial waters away from the influence of emergent land masses."

The results of the longline fishing have been described by Murphy and Shomura (1953); the detailed plankton studies will be reported later.

The station pattern for the oceanographic phase of cruise 11 was planned to duplicate the positions of the fishing stations occupied along the southbound leg. The positions of the fishing and oceanographic stations are shown on figure 1 (all figures are grouped at the end of the text). The data for the 22 stations appear in tabular form at the end of this report. These data, along with those from the bathythermograph lowerings, are represented by vertical sections, figures 2, 3, and, 7 to 12.

In the vertical sections, the position of each sample is indicated by a dot. If for some reason (thermometer stuck, Nansen bottle leaked, bottle pretripped, etc.) it can be definitely ascertained that the value for the particular field is in error, it is discarded, the dot is not carried, and the deleted value is indicated by a dash in the tabulated data. If a particular value is in doubt, but there is no apparent reason for its being in error, the dot is shown, the value is carried in the tabulated data and an appropriate footnote appended.

Temperature: The temperature sections, figures 2 and 3, have been constructed from bathythermograph observations. The data for figure 2 were collected during the southbound leg of the cruise (fishing) and those for figure 3 during the northbound leg (oceanography). The isotherms are plotted at 2-degree (F.) intervals; the maximum depth of penetration is indicated by a dash.

During the southbound leg of the cruise, five BT's were taken at the positions of each fishing station, and one at each 10-mile interval between stations. The data are plotted at 30-mile intervals in figure 2. During the return section lowerings were made at 10-mile intervals between 5° S. and 12° N. and at 30-mile intervals from 12° N. to 19° N. All lowerings are plotted in figure 3.

The most striking features of the two vertical temperature sections, reading north to south in figures 2 and 3, are (1) the shallow, well developed thermocline in the region of the northern boundary of the Countercurrent, and (2) the cooling of the surface water in the region of the equatorial divergence. Typical temperature-depth traces, reconstructed from BT's taken in these regions, are shown on figure 4.

In comparing the two sections, the change in the vertical distribution of temperatures during the period between the two sections is evident. Of particular interest are the changes in slope of the transition layer in the Countercurrent and the meridional shift in the center of the upwelling. In figure 5, plots of the 60°, 70°, and 80° F. isotherms for each leg of the cruise, are given to show these changes.

The wind data from both the southbound and northbound legs are summarized in figure 6. The values from which the arrows were plotted are listed in Table I at the end of the report.

Wind speed and direction were recorded at each bathythermograph lowering. These data were averaged for the total lowerings between each degree of latitude; the speed and direction were averaged separately. When there was a significant change in either speed or direction within 1 degree of latitude, i.e., 8° - 9° N., southbound section, less than the normal spacing of 1° of latitude was used.

Resultant winds were not calculated, as the observational accuracy does not warrant this treatment and as the change in either speed or direction within the 60-mile limits was usually within the accuracy of measurement. The data for each observation (number of observations shown at base of arrows) are available at the POFI, the Scripps Institution of Oceanography, and the U. S. Navy Hydrographic Office.

During the southbound leg the winds were predominantly from the NE to about 8° N., at which time they became light and variable and continued so to about 4° N. From 4° N. to the southern limit of the section the general direction shifted from southeasterly to easterly. Along the northbound leg the arrows show predominantly NE to E. winds.

Sigma-t, salinity, inorganic phosphate, and oxygen: Montgomery (1954) points out the desirability of presenting the several variables, i.e., temperature, salinity, phosphate, etc., in such a manner that the consistency among the several fields is readily visible. This can most easily be achieved by selecting a reference variable, and in this report sigma-t was the choice.

The data for sigma-t at an isopleth interval of 0.2 g/l, as read from plots relating temperature, salinity, and sigma-t (Cromwell 1954, fig. 1), were plotted for each station along with the observed values. The isopleths were then drawn (fig. 7). There was some smoothing, but with no violation of the observed points.

The points for the salinity (0.2 °/oo isopleth interval) were taken from the T/S curves, and those for phosphate (0.2 µg at/l isopleth interval) and oxygen (0.5 ml/l isopleth interval) were read from the station curves and plotted. In each case the observed values were also plotted. Finally, the section plots for each of the three fields, salinity, phosphate, and oxygen, were in turn placed over the sigma-t profile and isopleths drawn allowing them to run smoothly and as nearly parallel with those of the sigma-t surfaces as possible without violating the observed points (figs. 8-10). Each of the fields was plotted only to a depth of 500 meters, thus permitting greater detail within the transition layer.

The principal feature of the sigma-t profile (fig. 7), as with the previously described temperature sections, is the well developed gradient which lies at a minimum depth at the northern boundary of the Countercurrent (10° N.), deepening to the south, with the maximum depth at the southern boundary of the Countercurrent (5° N.). North of 10° N., i.e., in the North Equatorial Current, the distribution of the sigma-t surfaces with depth results in a less well defined density gradient. At the Equator, the equatorial divergence is reflected in a slight "doming" of the sigma-t surfaces.

The salinity maximum at about 150 meters, 2° to 5° S. (fig. 8), corresponds with that shown by Cromwell (1951, figs. 12 and 13), Cromwell (1954, figs. 8, 18, and 30) and by Mao and Yoshida (1953, fig. 15). In Cromwell's 1954 report, a tongue of high salinity (34.8 °/oo) is continuous from the northern to the southern limits of the sections; in the 1951 report, the bridge is continuous on the section along 172° W. longitude but interrupted between about 15° N. and 9° N. on along the 158th meridian. Similarly, although the situation is less well defined, in figure 8 of the present report the tongue of high salinity is interrupted between 13° N. and 8° N. The deep tongue of low salinity water (34.2 °/oo) centered at about 300 m., 19° N., is rather characteristic of this area in equatorial Pacific. The same may be said for the low salinity waters at the surface between 5° N. and 12° N., the zone of the Equatorial Countercurrent and the high rainfall belt.

The values for surface phosphates along the section (fig. 9) are somewhat irregular, but there is evident enrichment of the surface layers immediately south of the Equator (0.6 to 0.8 µg at/l), with a decrease to 0.2 µg at/l in the northern half. At about 8° - 9° N., the boundary zone between the North Equatorial Current and the Equatorial Countercurrent, the cooler, nutrient-enriched waters are to be found slightly above 100 meters, but do not reach the surface.

As was the case with several previous sections in the mid-Pacific equatorial region (Sverdrup et al. 1946, Cromwell 1951), there is direct evidence of upwelling immediately south of the Equator with the deeper, cooler, nutrient-rich waters replacing those at the surface.

Although a rigorous definition of upwelling is not possible at this time, mention should be made of the present apparent ambiguity with respect to the term. Sverdrup et al. (1946, p. 501) describe upwelling off the coast of California as the replacement of the light surface water by heavier sub-surface waters. At the Equator, the deeper waters are mixed into the surface layers from depths not exceeding 200 to 300 meters. Sverdrup and Fleming (1941, p. 317) propose that the replacement of the surface waters should be differentiated from the increase (or decrease) in slope of the isotherms and isohalines resulting from current transport, and suggest that once a transport has reached a steady state the vertical displacement of the isopleths will stop and "the process cannot be called upwelling." This same line of reasoning is undoubtedly applicable when considering the upwelling associated with the equatorial divergence and the increase or decrease in slope of the isotherms and isohalines associated with the mid-Pacific zonal circulation (see fig. 5).

We find both of the above-mentioned phenomena in the meridional section described in this report. Near the Equator there is upwelling associated with a wind-induced divergence. The deeper waters mix with those at the surface, resulting in a cooling of these surface waters and an increase in nutrients, such as phosphates, and conditions favorable to increased biological productivity ensue (King 1953, Murphy 1953, Sette MS).

Throughout the region of the Countercurrent the second phenomenon, that of a vertical displacement of the isopleths associated with zonal flow, is to be found. The sigma-t surfaces (fig. 7) slope markedly, the 24 g/l surface rising from 525 meters at 5° N. to 50 meters at 9° N. The 2.0 µg at/l phosphate isopleth (fig. 9) is near 300 meters at 4° N., sloping upward to 100 meters at 9° N. To this situation Dietrich (1935, p. 57) assigns the term "dynamically caused upwelling." Even if there is occasional cooling and enrichment of surface waters at the boundary of a zonal current, such as the Equatorial Countercurrent, it is believed that any use of the term upwelling is confusing.

Although the data on file at POFI require considerable further study, there is little evidence that there is any mixing of the deeper waters with the surface waters at the northern edge of the

Equatorial Countercurrent. However, one must not overlook possibility that a shallow density gradient (fig. 7) coupled with strong winds might result in mixing of surface and deeper waters and produce a transient enrichment of surface waters. Also, horizontal eddies (Cromwell 1951, Mao and Yoshida 1953) may effect a similar condition. Although deeper waters do not normally reach the surface in this region, the distribution of mass resulting from the zonal currents brings enriched waters into the subsurface euphotic zone. The biological significance of this vertical displacement is not well understood and requires considerable further study.

The principal features of the vertical distribution of oxygen (fig. 10) are the relatively high values at or near the surface (4.0 - 4.5 ml/l) and the oxygen-minimum layer at intermediate depths. An oxygen-rich layer is encountered at depths below 500 meters (see tabulated station data). The subsurface layer of higher oxygen concentrations, 5.0 to 5.7 ml/l, centered at 100 meters between 19° N. and 14° N., may be associated with the intrusion of the northern subtropical water mass, while the inclination of the oxygen isolines in the same latitudes but below 100 meters suggests an association with an intermediate water mass. Comparison at the Equator of figures 7 and 10 suggests the mixing of upwelled waters of relatively low oxygen content with those at the surface.

Currents: The dynamic topography is shown on figure 11, the geostrophic current velocities on figure 12. The actual results of the dynamic calculations are plotted in the former in order that the degree of smoothing of the isolines may be observed. The data for the stations at the Equator and at 1° N. latitude were insufficient for calculations to the 1,000-decibar surface (see footnote in tabulated data for stations 33 and 34). Because of the uncertainty of relative current computation for stations near the Equator, the isovels between 3-1/2° N. and 3-1/2° S. have not been included in figure 12.

In figure 12, only the major features of the velocity distribution as computed by the dynamic calculations are to be considered reliable. Internal waves undoubtedly exert a strong, but quantitatively unknown influence.

The most striking feature on both figures is the evidence of the Countercurrent flowing strongly to the east between 5° N. and 10° N., with the highest velocity of 80 cm. per second near the southern boundary. This velocity may be somewhat low, as the plotted velocities represent an average between successive stations. Another easterly flow, but of very small magnitude, is indicated between 17-1/2° and 19-1/2° N. The North Equatorial Current exists in a broad band between 10° and 17-1/2° N. with velocities of 23 cm./sec. or less.

The Countercurrent is strongest near its southern edge, with a maximum speed of 80 cm./sec. between 55 and 75 meters. The 10 cm./sec. isovel reaches the 700-decibar surface immediately below the band of highest velocity, while at the northern edge the 7 cm./sec. level is between 25 and 50 meters with the bottom of the current (0-10 cm./sec.) below the 700-decibar surface. Considerably higher speeds are indicated down to the 700-decibar surface in the South Equatorial Current.

It is difficult to discuss the flow south of 5° N., the region of the South Equatorial Current, with any degree of certainty. The loss of data from the stations at the Equator and 1° N. precludes drawing of the dynamic topography through this area. This is unfortunate, as inspection of figure 12 shows a considerable difference in level across this region. Figure 12 indicates a moderately strong westerly flow between the southern boundary of the Countercurrent and 3° N. and a westerly flow with velocities over 60 cm./sec. between 3° S. and 5° S. About all that can be said with certainty is that the South Equatorial Current was present during the time of the cruise.

Supplementary information on the velocities of the currents may be determined from the drift of the longline gear (Austin MS) used for sampling the fish population (gear described by Niska 1953) and from the drift of the vessel while on oceanographic stations. The former, in view of the relatively small effect of windage on the 8-mile length of the longline, yields a reliable estimate of both speed and direction of the current integrated over the depth of the lines (100 to 300 feet). The information from vessel drift is less reliable because of the quantitatively unknown effect of wind and the fact that the determination of drift included running time between fixes.

Of particular interest on figure 2, upper panel, is the westerly set (North Equatorial Current) between 15° N. and 9° N., the easterly set (Equatorial Countercurrent) between 8° - 9° N. and 5° - 6° N., and the westerly set (South Equatorial Current) south of this latitude. Attention is called to the easterly set (109° T.) at the Equator, which is significant when considering the submerged countercurrent (the undercurrent) reported by Cromwell et al. (1954). Also the three northernmost stations in the South Equatorial Current, particularly stations 9, 10, and 11 (fig. 1), exhibit a northerly component, while those south of the Equator (25-27) show a southerly component (Cromwell 1953).

When possible to calculate from available navigational data, the direction of drift while on oceanographic stations was determined and entered to the nearest cardinal point in the upper panel of figure 3. No reliable data were available for 10° N. nor south of 1° N. latitude. The easterly drift of the Countercurrent is evident for stations at 6° and 7° N. latitude. The results for 8° N. yielded a set of 270° T., but if the effect of the wind could be accurately determined, it is believed the resultant current set would be to the east. At 5° N., apparently at the boundary between the South Equatorial Current and the Equatorial Countercurrent, the net drift was zero.

As pointed out by Cromwell (1951), information concerning the currents may be inferred from the wire angles during an oceanographic cast. The average wire angle for all stations in the North Equatorial Current was 23°, the wind speeds on station were 17 - 19 knots, blowing from the northeast. In the Countercurrent, with winds from 14 - 19 knots from NE to ENE, the average wire angle was 12°. Considering the westerly moving North Equatorial Current and the easterly Countercurrent, this was as could be expected.

Moving south from the southern edge of the Countercurrent (5° N.) into the South Equatorial Current, the wire angle increased from station to station from 20° at 5° N. to 65° at the Equator. The wind, from E. to ESE, was between 13 and 16 knots. Considering that the minimum wire angles were found in the region of the maximum velocity of the South Equatorial Current (the northern edge) and that there was no appreciable change in wind between the northern edge of the South Equatorial Current and the Equator, it is possible that the large angles near the Equator were related to the undercurrent reported by Cromwell et al. (1954). South of the Equator (2° S.) the angle fell to 10° (wind 08 knots) and increased to 35° at 5° S. (wind 18 knots). This latter angle is similar to that at stations with similar winds in the North Equatorial Current.

Discussion

Sette (MS), in a recent paper discussing the work of the Pacific Oceanic Fishery Investigations, states that the survey data from the east central equatorial Pacific "demonstrate that divergence and upwelling at the Equator enrich the surface waters with inorganic nutrient salts stimulating plankton production. Surface waters containing plankton drift northerly to an adjacent convergent zone. By inference this is believed to maintain a concentration of organisms of the trophic level above plankton, mainly small fish and squid, which in turn comprise food for yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel). The system is generated and its structure largely governed by the winds."

Figure 13, in effect, summarizes the data from Hugh M. Smith cruise 11 and lends support to the above quotation. In this figure, surface values for temperature, salinity, oxygen, and phosphate, the current speed, the zooplankton volumes, and the yellowfin catch have been plotted against latitude (vertical scale). The first five fields plotted, namely, T, S, 0_2, $P0_4$, and current speed represent conditions as observed during the period of the cruise. The zooplankton, although sampled during the cruise, may be considered as the culmination of a series of events which had their origin during some previous period of upwelling, probably some distance to the east. The charge of nutrients thus brought to the surface was utilized by phytoplankton, and indirectly for the succeeding trophic levels, zooplankton, forage fish and squid, and the tuna.

Although we do not know the time required for the conversion of nutrients through the trophic levels to the tuna, the data presented in figure 13 suggest the integrated relationships among the oceanographic and the biological factors. The curves for the various fields (fig. 13) nicely define the zones of interest. Reading from north to south (top to bottom) the North Equatorial Current extends south to about 10° N., the Equatorial Countercurrent between 10° N. and 5° N., and the South Equatorial Current from 5° N. to the southern limit of the section. The equatorial divergence is centered at 1° S. with the zone of convergence between this latitude and the southern boundary of the Countercurrent. Within the Countercurrent the salinity curve shows the typical increase toward the southern edge. The values for surface phosphates, associated with the center of upwelling, are somewhat atypical, with higher than usual values from the southern boundary of the section and lower values between the upwelling and the southern boundary of the Countercurrent. Several reasons for this could be advanced including mixing with surface waters of lower $P0_4$ during the meridional transport (1° to 5° N.), variations in intensity of upwelling from cruise to cruise, and a reflection of the biological activity in the waters moving in from the east.

The latitudinal variations in the abundance of zooplankton (fig. 13F) lend emphasis to the proposition of enrichment from the equatorial divergence. A more detailed discussion of this relationship between the plankton and the fish in this area is to be found in the report by Murphy and Shomura (1953) and in the report by Sette (MS).

Acknowledgements

A report of this nature results from the combined efforts of many individuals. Mr. Townsend Cromwell, as field party chief, was largely responsible for the successful completion of the program aboard the vessel. Mary Lynne Godfrey, E. D. Stroup, D. Ching, and others processed the data. Tamotsu Nakata prepared the illustrations.

No sea-going program could be successful without the cooperation of the vessel personnel. Special thanks are due to the master and crew of the M/V *Hugh M. Smith*.

The efforts of the above, and of many others, are gratefully acknowledged.

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Table I (A)
(Southbound)

Average wind direction and speed for observations recorded between latitudes listed in column 1

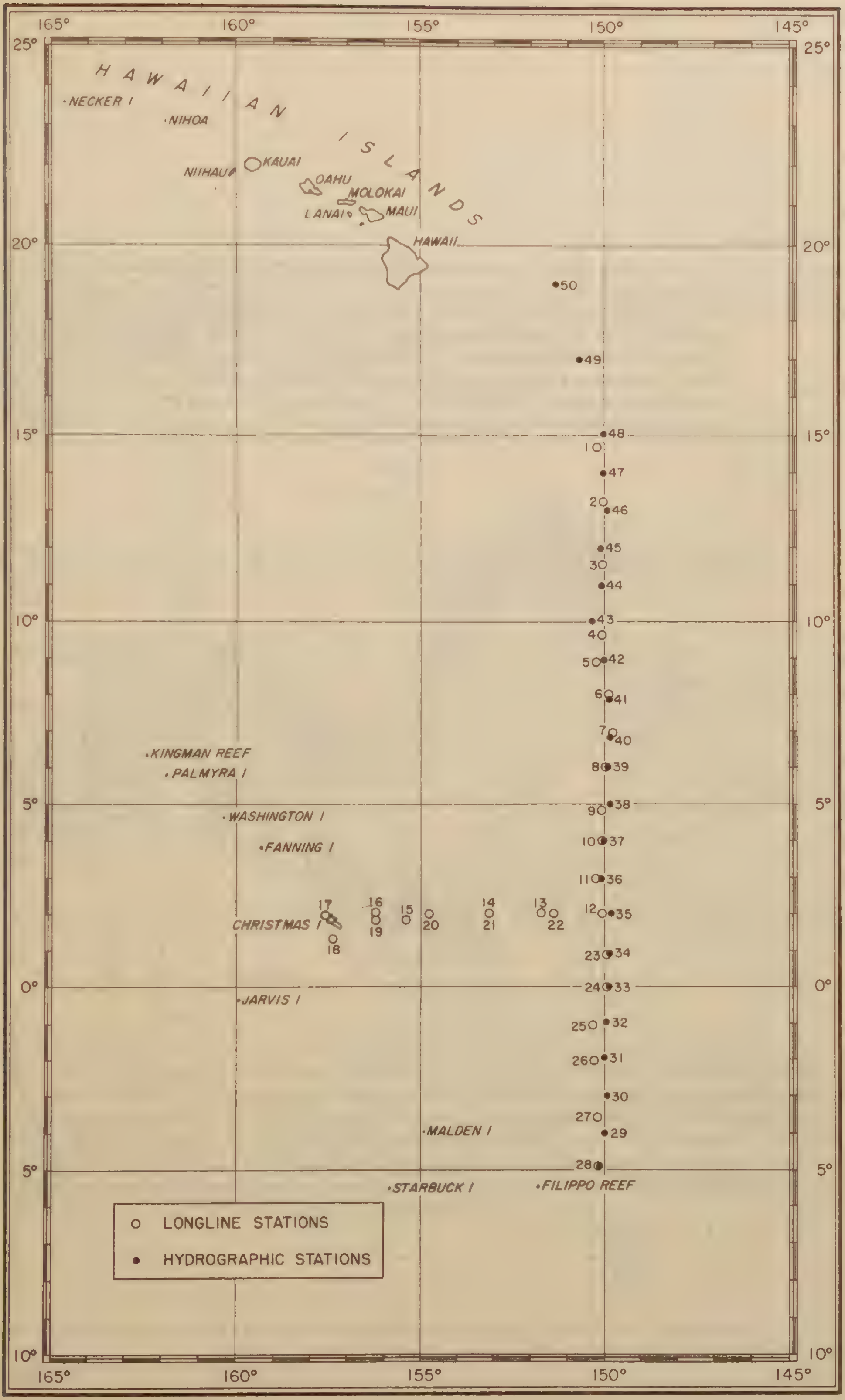
Position (along 150°W. longitude)	Average direction °T	Average speed, knots	Number of observations
19°07'N	60	15	1
18°06'N	60	19	3
17°00'N	60	20	3
16°04'N	60	17	3
15°09'N	50	22	3
14°15'N	60	21	6
13°06'N	70	16	6
12°10'N	80	12	7
11°13'N	70	16	7
10°08'N	70	12	4
9°11'N	40	17	8
8°58'N	35	16	5
8°17'N	25	14	4
7°57'N	50	06	5
7°08'N	190	04	5
6°00'N	150	06	14
5°04'N	180	05	5
4°31'N	200	08	7
4°00'N	160	14	8
3°10'N	150	13	5
2°11'N	140	15	10
To Christmas Island and return			
0°00'	120	14	10
0°52'S	120	17	9
1°59'S	100	19	10
2°52'S	110	18	8
3°37'S	120	16	7
4°57'S	100	16	6

Table I (B)
(Northbound)

Position (along 150°W. longitude)	Average direction °T	Average speed, knots	Number of observations
4°57'S	110	18	1
4°00'S	75	08	7
3°00'S	80	07	7
2°00'S	100	08	7
1°00'S	130	09	7
0°01'N	120	14	7
1°02'N	90	16	7
2°10'N	90	15	7
3°00'N	100	16	6
3°58'N	100	15	7
4°59'N	90	13	7
5°56'N	70	14	7
6°51'N	70	17	7
7°51'N	70	17	7
8°57'N	50	17	7
10°00'N	60	19	7
10°57'N	60	17	7
11°59'N	70	19	7
13°00'N	60	17	3
14°01'N	60	18	3
15°01'N	70	19	3
16°05'N	80	19	2
17°00'N	60	18	3
18°00'N	90	19	2
19°00'N	80	16	3

Figures

1. Station chart.
2. Temperature section (southbound).
3. Temperature section (northbound).
4. Representative BT traces.
5. Comparison, northbound and southbound vertical temperature sections.
6. Wind vectors, northbound and southbound sections.
7. Vertical section, sigma-t.
8. Vertical section, salinity.
9. Vertical section, phosphate.
10. Vertical section, oxygen.
11. Dynamic topography.
12. Current velocity section.
13. Summary of various oceanographic and biologic data, northbound and southbound sections.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LANAI
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KINGMAN REEF
PALMYRA I
WASHINGTON I
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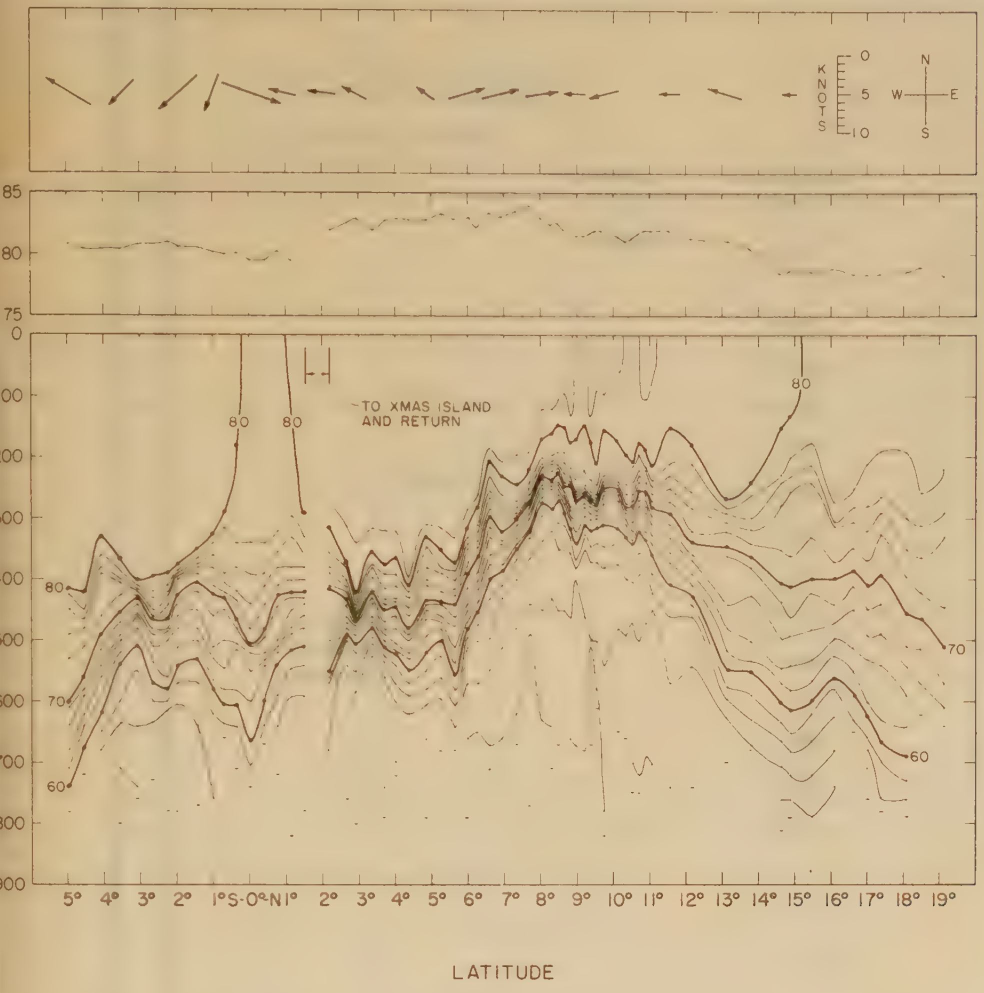
○ LONGLINE STATIONS
● HYDROGRAPHIC STATIONS

Fig. 1.-- Track chart, Hugh M. Smith cruise 11, August 20 through October 6, 1951. Open circles indicate positions of fishing stations (stations 1-28, August 24 - September 25, 1951); solid dots, the positions of the hydrographic stations (stations 28-50, September 26 - October 4, 1951.)



ig. 2. -- Upper panel - direction and speed of longline drift at position of selected fishing stations (1-12, 23-28) shown on figure 1. Center panel - surface temperatures recorded at position of bathythermograph lowerings during southbound section (fishing), Hugh M. Smith cruise 11. Lower panel - bathythermograph section, southbound section, Hugh M. Smith cruise 11. Isotherm interval 2.0° F., depth of lowering indicated by small horizontal dash. The break in the section, between 1° and 2° N. latitudes, represents period of cruises from 150° W. longitude to Christmas Island and return (stations 12-23, September 4-19, 1951) (fig. 1).

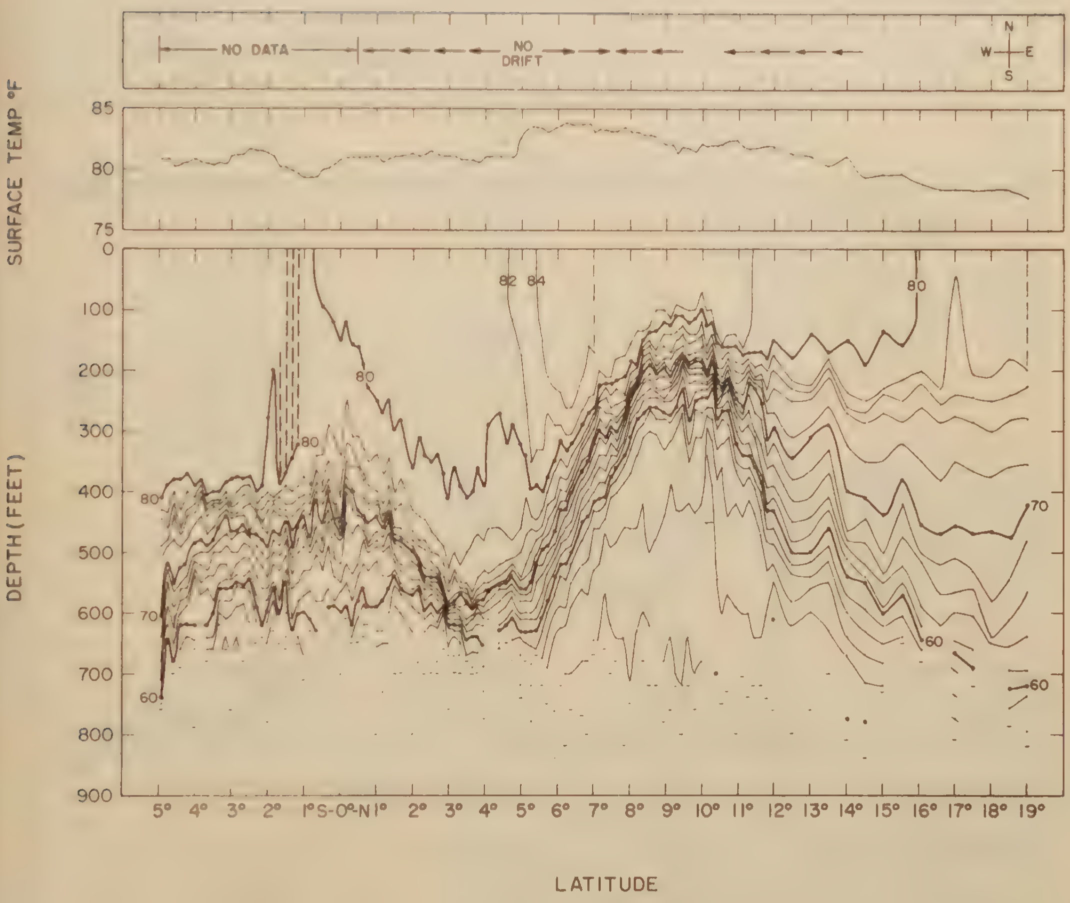


Fig. 3. -- Upper panel - direction of drift of Hugh M. Smith during period on oceanographic stations. Center panel - surface temperatures as measured at each bathythermograph lowering. Lower panel - bathythermograph section, northbound section, Hugh M. Smith cruise 11 (stations 28-50, September 25 - October 4, 1951). Isotherm interval 2.0° F., depths of lowering indicated by small horizontal dash. Vertical dashed lines denote homogeneous water with the same temperature as that of the isotherm intersected by the dashed line.

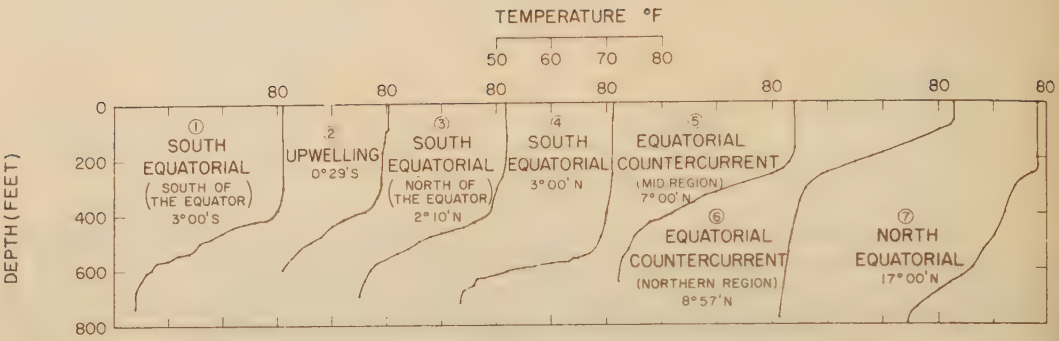


Fig. 4. -- Typical bathythermograph traces for various regions crossed during Hugh M. Smith cruise 11.

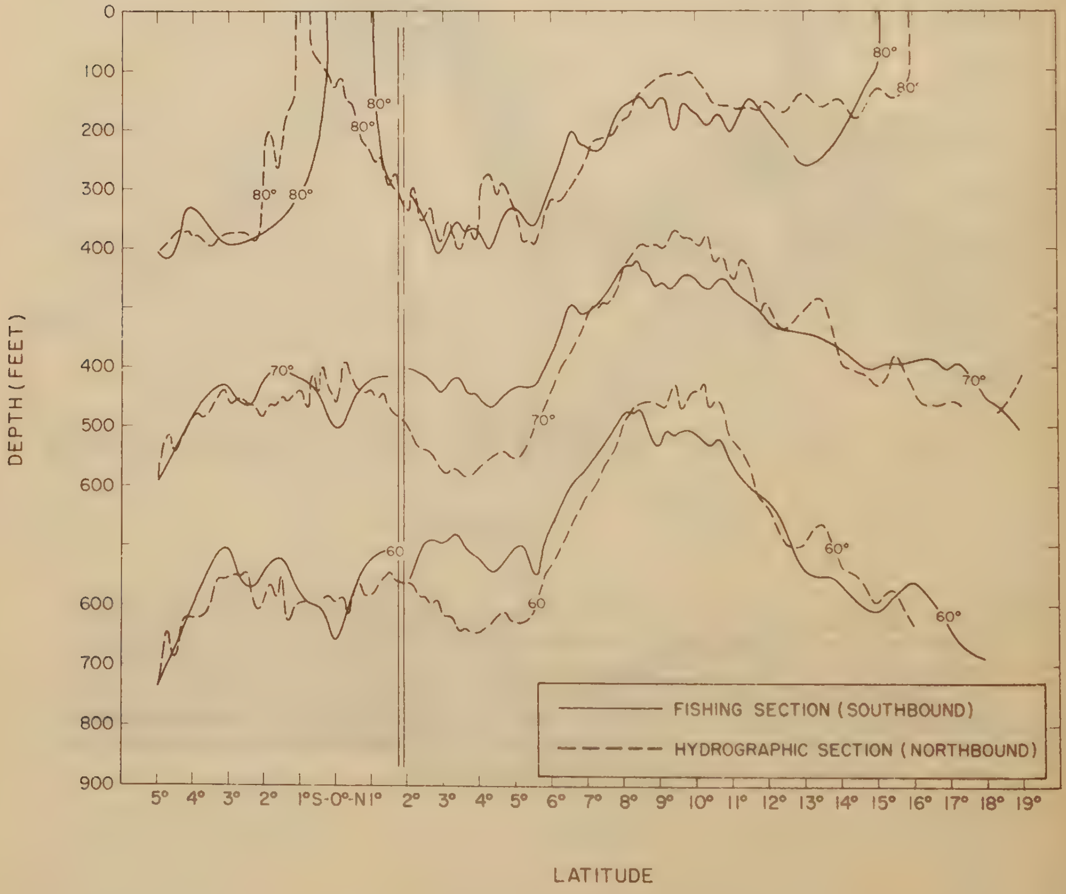


Fig. 5. -- Comparison of the 60°, 70°, and 80° F. isotherms for southbound (solid line) and northbound sections (broken line).

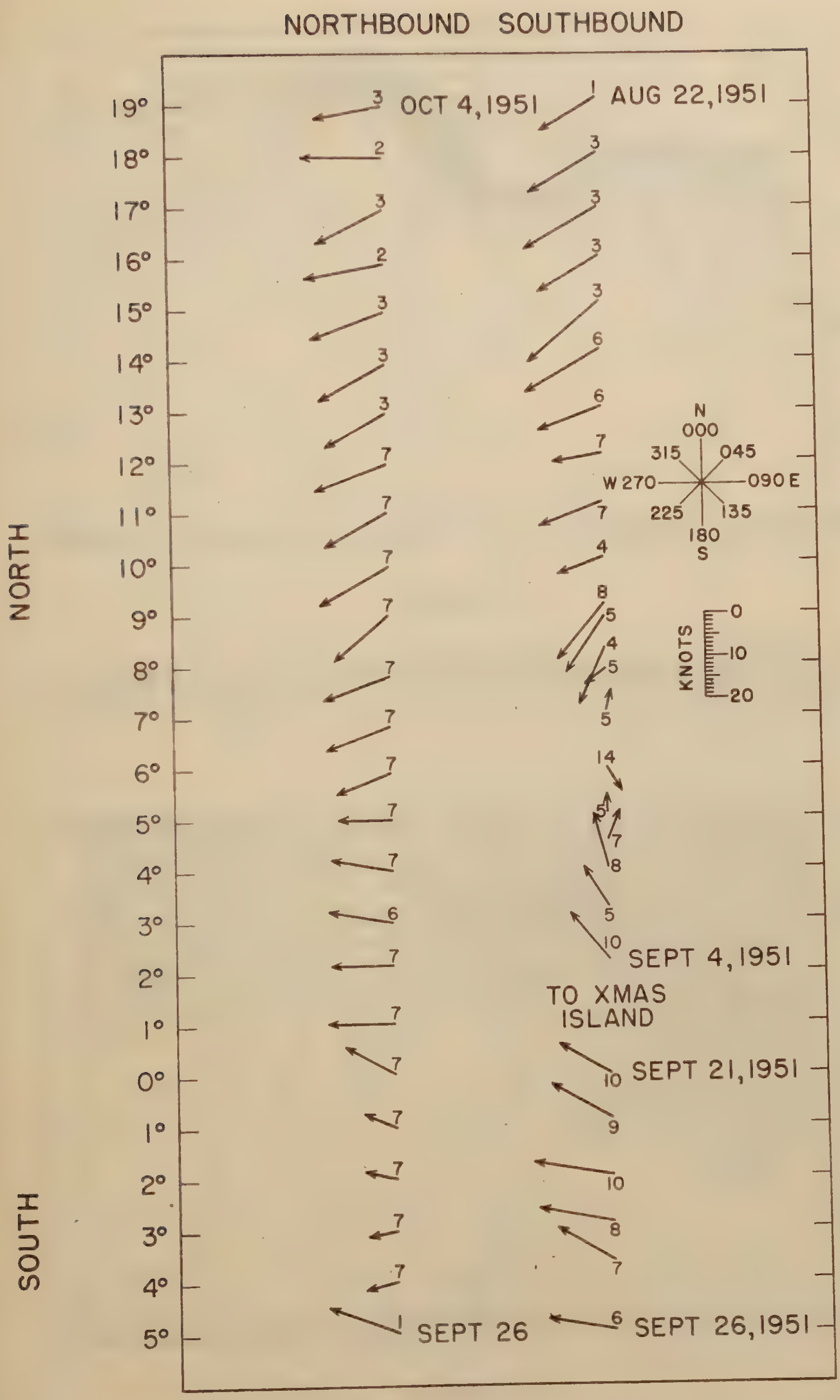


Fig. 6.-- Wind and direction and speed, Hugh M. Smith cruise 11, northbound and southbound sections. Each arrow represents independent averages of speed and direction for total observations between arrows. The figure at the base of the arrow denotes the number of observations included in the averages.

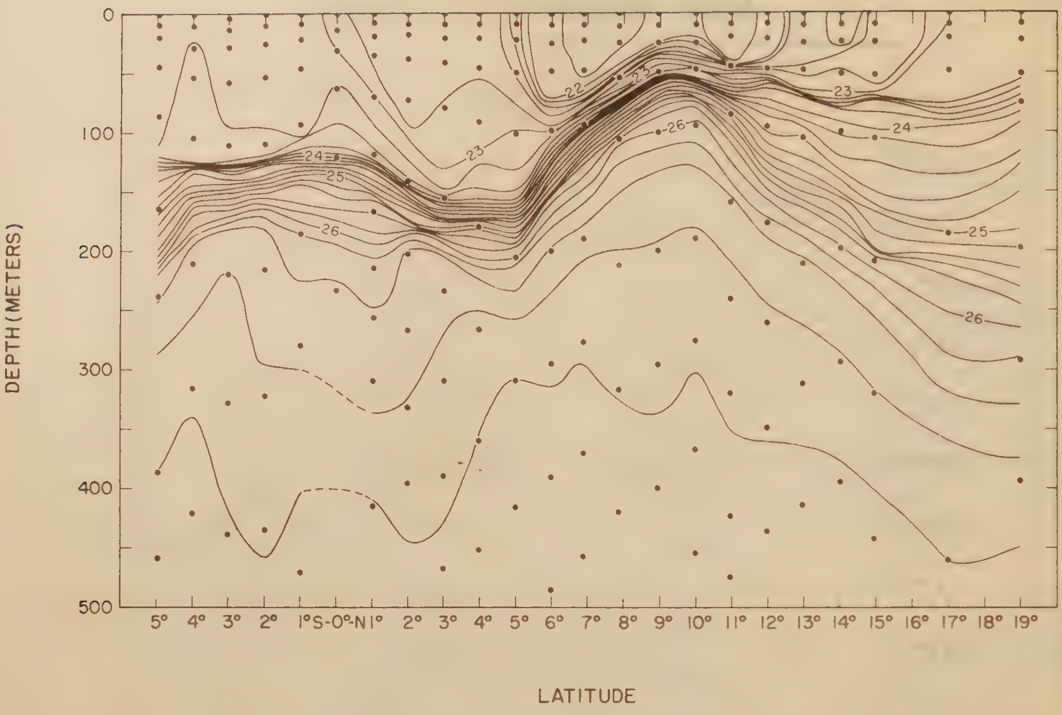


Fig. 7.-- Sigma-t, Hugh M. Smith cruise 11, stations 28-50, 5° S. - 19° N., 150° W. longitude, September 26 through October 4, 1951. Sigma-t in grams per liter, isopleth interval 0.2 gm./l.

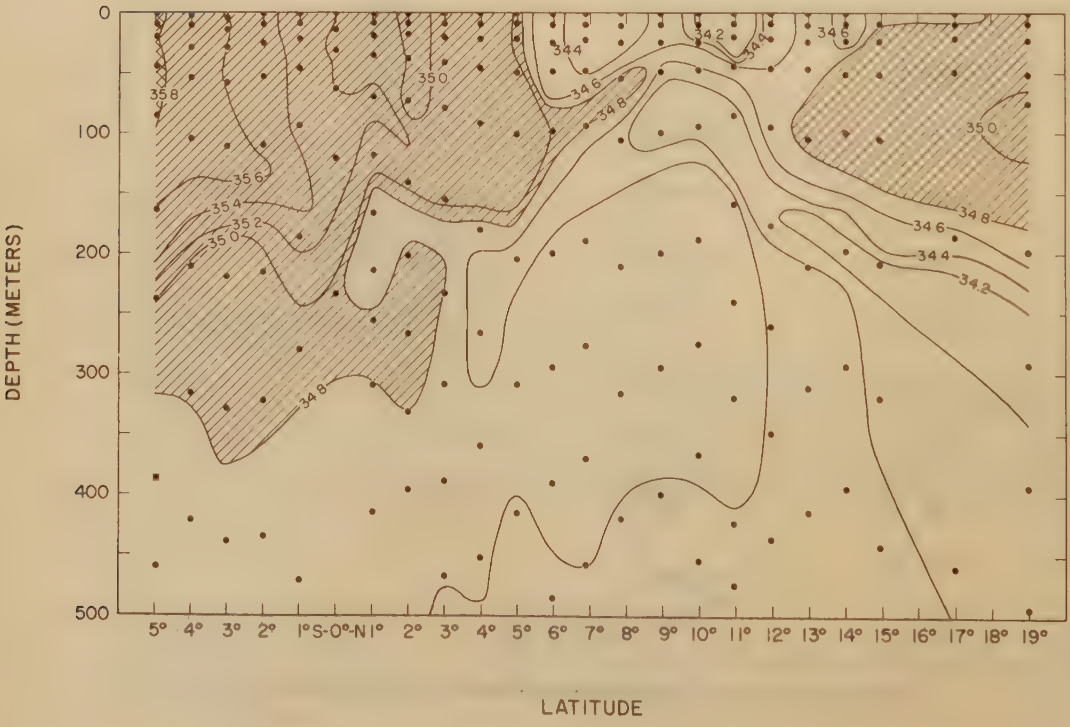


Fig. 8.-- Salinity, Hugh M. Smith cruise 11, stations 28-50, 5° S. - 19° N., 150° W. longitude, September 26 through October 4, 1951. Salinity in parts per thousand, isopleth interval 0.2 °/oo.

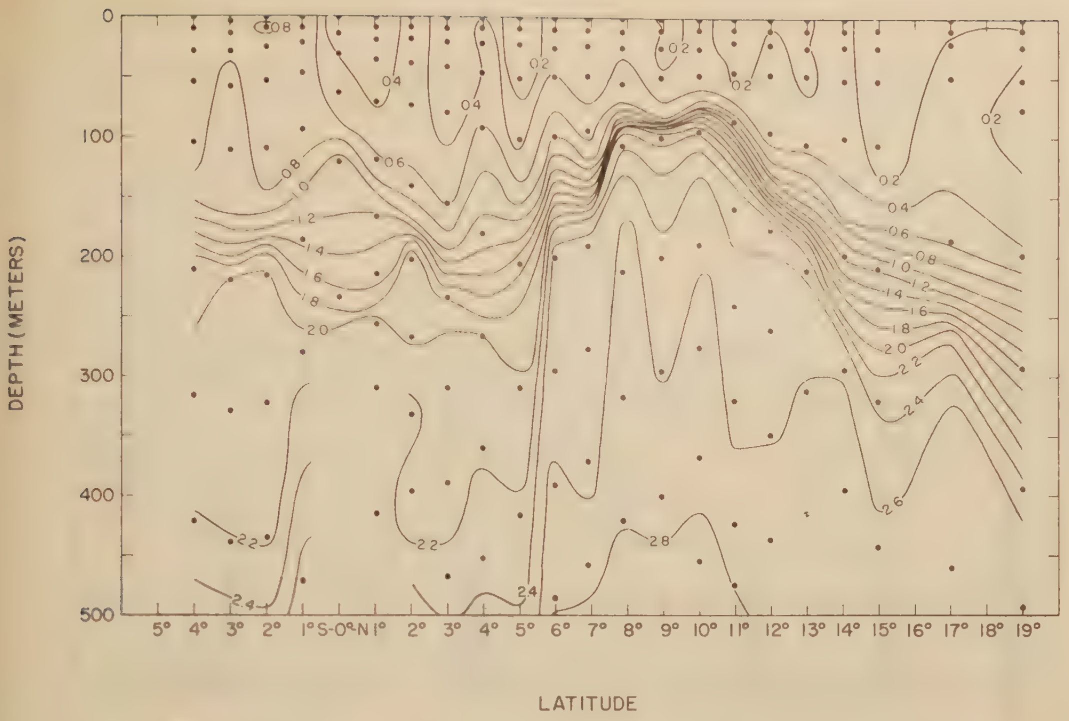


Fig. 9.-- Inorganic phosphate, Hugh M. Smith cruise 11, stations 28-50, 5° S. - 19° N. latitude, 150° W. longitude, September 26 through October 4, 1951. PO_4 in microgram atoms per liter, isopleth intervals 0.2 μg at/l.

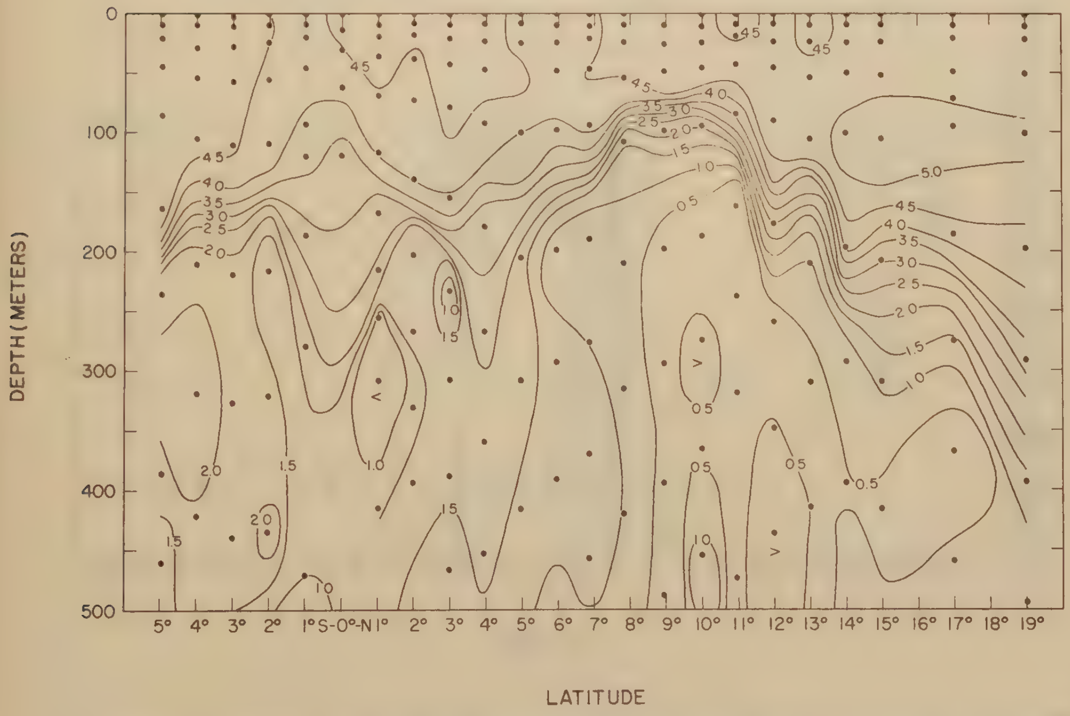


Fig. 10.-- Dissolved oxygen, Hugh M. Smith cruise 11, stations 28-50, 5° S. - 19° N. latitude, 150° W. longitude, September 26 through October 4, 1951. Oxygen in milliliters per liter; isopleth intervals 0.5 ml./l.

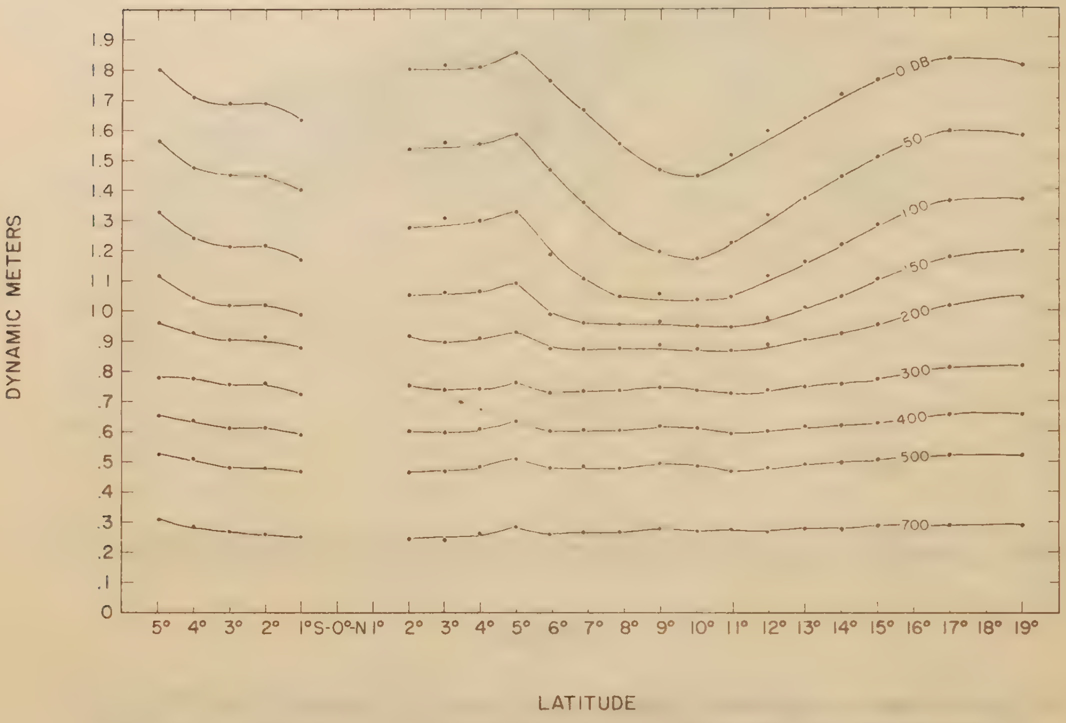


Fig. 11. -- Smooth profiles of the isobaric surfaces relative to the 1,000-decibar surface, Hugh M. Smith cruise 11, stations 28-50, 5° S. - 19° N. latitude, 150° W. longitude, September 26 through October 4, 1951.

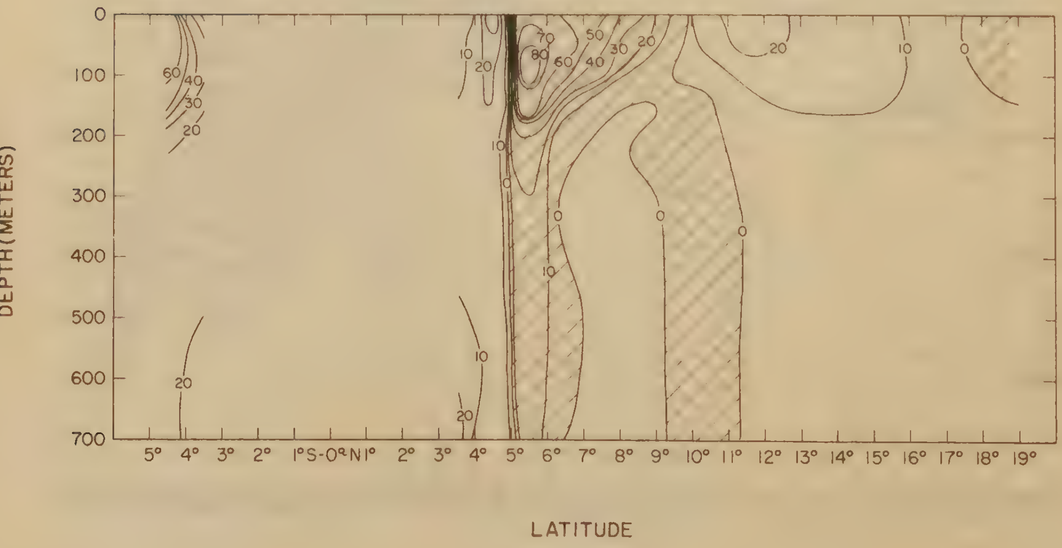


Fig. 12. -- Vertical section, geostrophic currents, Hugh M. Smith cruise 11, based on the smooth profiles (fig. 11). Current speed indicated in centimeters per second.

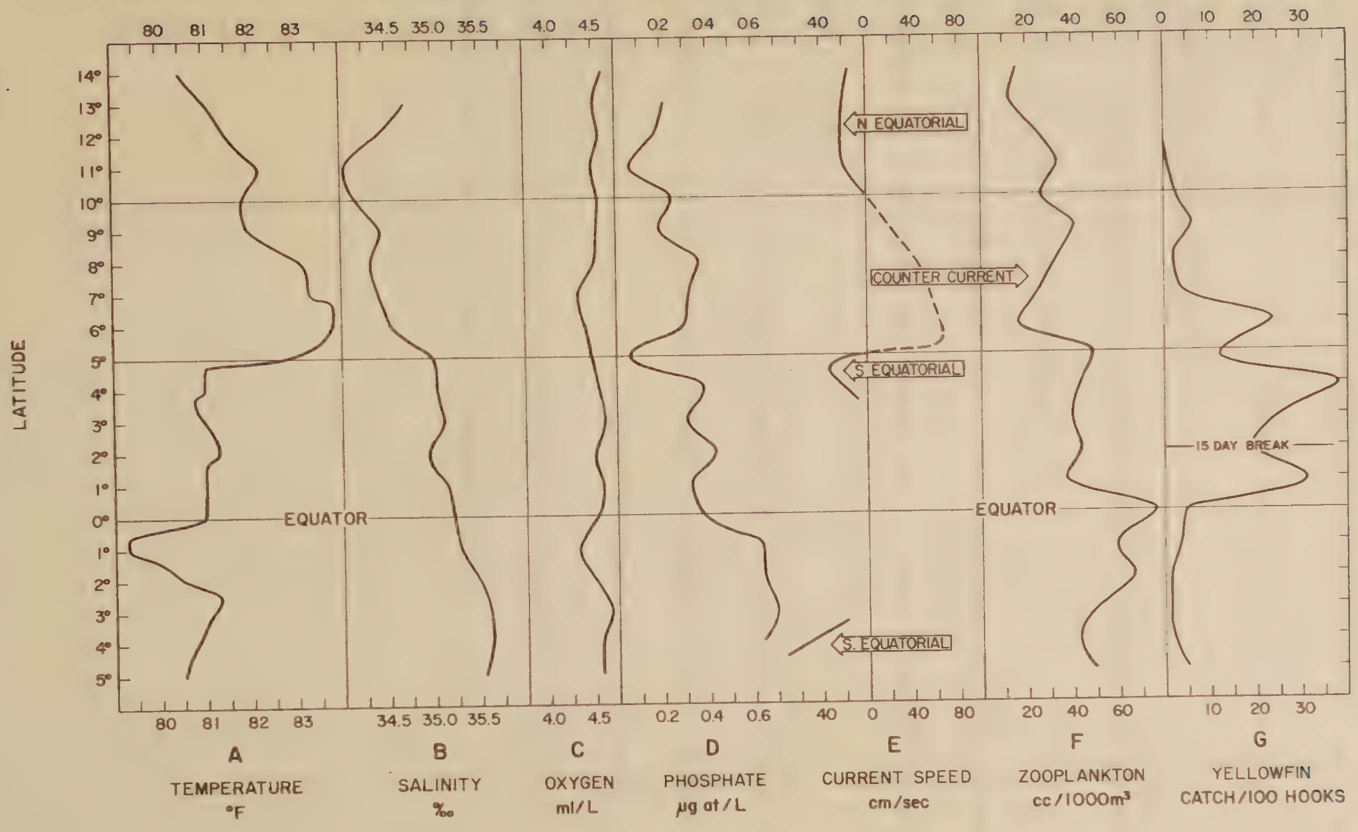


Fig. 13.-- Summary of various oceanographic and biological data, Hugh M. Smith cruise 11. Northbound section, panels (A) through (F), southbound section panel (G).

Remarks about the oceanographic data

Weather was recorded according to the ww code as it appears in The U. S. W. B. Circular M, Instructions to Marine Meteorological Observers.

Wind velocity was measured using an anemometer located 30 m. above the sea surface.

In the tabulated data, the horizontal line(s) between depths separates the two or more casts necessary during the particular station.

Whenever there is no doubt concerning data being in error (Nansen bottle pretrip, bottle leakage, etc.), these data are not carried in the tabulations and a footnote is appended. If values are doubtful, but there is no positive evidence of an error, the data are carried with appropriate footnotes.

STATION 28

M/V Hugh M. Smith: Cruise 11, 04°57'S, 150°04'W, September 25, 1951. Messenger time: 1818 GCT. Weather: 02, cloud coverage 4. Wind: 110°, 18 kt. Sea: 1-3 ft. Wire angle: 35°. Depth of water: no data

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O2 (ml/l)	PO4-P (μg at/l)
00	27.10	35.55	23.13	4.55	
09	27.10	35.57	23.14	4.56	
21	27.10	35.59	23.15	4.56	
44	27.10	35.57	23.14	4.50	
86	27.11	35.59	23.15	4.56	
164	21.93	35.60	24.71	4.56	
237	13.37	35.02	26.35	1.87	
312	10.92	1/		1/	
386	09.70	34.71	26.79	1.75	
459	08.84	34.64	26.88	1.30	
597	07.26	34.61	27.10	1.93	
749	06.03	34.53	27.20	2.16	
921	05.12	34.54	27.32	2.48	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.10	35.55	23.13	0.000	1.799
10	27.10	35.57	23.14	0.048	1.751
20	27.10	35.59	23.15	0.095	1.704
30	27.10	35.59	23.15	0.142	1.657
50	27.10	35.57	23.14	0.237	1.562
75	27.10	35.58	23.14	0.357	1.442
100	27.08	35.59	23.16	0.476	1.323
150	23.32	35.61	24.32	0.687	1.112
200	18.83	35.48	25.45	0.842	0.957
250	12.74	34.98	26.45	0.945	0.854
300	11.17	34.83	26.63	1.023	0.776
400	09.53	34.70	26.82	1.151	0.648
500	08.30	34.63	26.96	1.278	0.521
600	07.20	34.61	27.11	1.391	0.408
700	06.38	34.55	27.17	1.494	0.305
800	05.74	34.54	27.24	1.592	0.207
1000	04.87	(34.54)	27.35	1.799	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 29

M/V Hugh M. Smith: Cruise 11, 04°00'S, 150°00'W, September 26, 1951. Messenger time: 0916 GCT. Weather: 02, cloud coverage 0. Wind: 090°, 8 kt. Sea: < 1 ft. Wire angle: 25°. Depth of water: no data.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
01	27.09	35.61	23.17	4.56	0.64
10	27.10	35.62	23.17	4.58	0.61
28	27.03	35.63	23.20	4.63	0.61
54	27.02	35.64	23.21	4.64	0.60
105	26.98	35.63	23.22	4.60	0.70
211	12.37	34.99	26.53	1.86	1.96
318	10.82	34.81	26.68	2.43	2.02
422	09.26	34.69	26.85	1.94	2.22
531	08.25	34.63	26.97	1.77	2.60
635	06.94	34.52	27.07	1.33	2.75
848	05.52	34.51	27.25	1.98	2.77
1058	04.38	34.56	27.42	2.18	2.70
1265	03.70	1/		2.38	2.39

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.09	35.61	23.17	0.000	1.709
10	27.10	35.62	23.17	0.047	1.662
20	27.08	35.63	23.19	0.094	1.615
30	27.03	35.63	23.20	0.141	1.568
50	27.02	35.64	23.21	0.235	1.474
75	27.00	35.64	23.22	0.352	1.357
100	26.98	35.63	23.22	0.470	1.239
150	20.89	35.58	24.98	0.668	1.041
200	12.78	35.04	26.48	0.784	0.925
250	11.70	34.90	26.58	0.861	0.848
300	11.04	34.83	26.65	0.936	0.773
400	09.58	34.71	26.81	1.076	0.633
500	08.51	34.65	26.94	1.202	0.507
600	07.37	34.55	27.03	1.320	0.389
700	06.48	34.51	27.13	1.429	0.280
800	05.83	34.51	27.21	1.530	0.179
1000	04.66	34.54	27.37	1.709	0.000

1/ Salinity sample bottle empty.

STATION 30

M/V Hugh M. Smith: Cruise 11, 03°00'S, 149°57'W, September 26, 1951. Messenger time: 1815 GCT. Weather: 02, cloud coverage 4. Wind: 090°, 9 kt. Sea: < 1 ft. Wire angle: 08°. Depth of water: no data.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
03	27.30	35.60	23.09	4.68	0.70
13	27.22	35.61	23.13	4.62	0.68
29	27.17	35.59	23.13	4.57	0.65
58	27.16	35.58	23.12	4.53	0.69
112	26.78	35.64	23.29	4.53	0.72
220	11.66	34.91	26.60	1.74	2.00
327	10.95	34.81	26.66	1.57	2/
438	09.83	34.78	26.83	1.99	
545	07.84	34.63	27.03	1.12	
651	06.65	34.58	27.16	1.55	
858	05.25	34.54	27.30	1.96	
1066	04.11	1/		1/	
1264	03.66	34.55	27.48	2.32	

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.30	35.60	23.10	0.000	1.687
10	27.25	35.61	23.12	0.048	1.639
20	27.20	35.60	23.13	0.095	1.592
30	27.17	35.59	23.13	0.143	1.544
50	27.16	35.58	23.13	0.238	1.449
75	27.12	35.59	23.14	0.358	1.329
100	26.93	35.61	23.22	0.476	1.211
150	20.25	35.55	25.13	0.675	1.012
200	11.96	34.95	26.58	0.786	0.901
250	11.42	34.37	26.61	0.861	0.826
300	11.10	34.32	26.63	0.935	0.752
400	10.28	34.79	26.76	1.079	0.608
500	08.61	34.68	26.95	1.209	0.478
600	07.16	34.60	27.10	1.322	0.365
700	06.29	34.56	27.19	1.424	0.263
800	05.60	34.54	27.26	1.519	0.168
1000	04.50	34.62	27.45	1.687	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.
2/ Phosphate sample useless due to addition of wrong reagents.

STATION 31

M/V Hugh M. Smith: Cruise 11, 02°00'S, 150°02'W, September 27, 1951. Messenger time: 0241 GCT. Weather: 02, cloud coverage 2. Wind: 120°, 9 kt. Sea: < 1 ft. Wire angle: 08°. Depth of water: no data

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.50	35.49	22.95	4.49	0.65
10	27.02	35.53	23.13	4.73	0.84
25	26.96	35.48	23.11	4.50	0.69
56	26.87	35.51	23.17	4.50	0.65
110	26.62	35.50	23.24	4.33	0.64
217	12.08	34.94	26.54	1.05	2.02
322	11.20	34.82	26.62	1.76	2.02
433	10.16	34.74	26.74	2.03	2.07
539	08.02	34.60	26.98	0.81	2.72
645	06.74	34.57	27.14	1.45	2.68
852	05.10	34.52	27.31	1.93	2.75
1059	04.24	1/		1/	1/
1263	03.58	34.59	27.52	2.26	2.69

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.50	35.49	22.95	0.000	1.688
10	27.02	35.53	23.13	0.048	1.640
20	26.98	35.50	23.12	0.096	1.592
30	26.94	35.48	23.12	0.144	1.544
50	26.88	35.49	23.15	0.239	1.449
75	26.81	35.51	23.18	0.357	1.331
100	26.72	35.51	23.21	0.475	1.213
150	19.31	35.51	25.35	0.670	1.018
200	12.42	34.98	26.51	0.777	0.911
250	11.80	34.91	26.57	0.854	0.834
300	11.37	34.84	26.60	0.930	0.758
400	10.54	34.77	26.69	1.079	0.609
500	08.77	34.64	26.89	1.215	0.473
600	07.23	34.58	27.08	1.332	0.356
700	06.26	34.55	27.19	1.436	0.252
800	05.43	34.52	27.26	1.531	0.157
1000	04.42	34.76	27.57	1.688	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 32

M/V Hugh M. Smith: Cruise 11, 01°00'S, 149°58'W, September 27, 1951. Messenger time: 1129 GCT. Weather: 01, cloud coverage not recorded. Wind: 130°, 9 kt. Sea: < 1 ft. Wire angle: 28°. Depth of water: no data

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.40	35.29	23.15	4.33	0.64
08	26.38	35.28	23.14	4.34	0.65
21	26.36	35.30	23.17	4.28	0.65
47	26.24	35.30	23.20	4.16	0.68
93	26.32	35.52	23.35	3.94	0.72
186	15.04	35.26	26.18	2.78	1.34
280	11.78	34.88	26.55	1.82	2.08
376	10.14	1/		1/	1/
471	08.50	34.64	26.93	1.00	2.69
563	07.51	34.60	27.05	1.02	2.80
750	06.02	34.56	27.22	1.78	2.78
943	04.82	1/	1/	1/	1/
1135	04.04	1/	1/	1/	1/

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.40	35.29	23.15	0.000	1.636
10	26.38	35.28	23.15	0.047	1.589
20	26.36	35.30	23.17	0.095	1.541
30	26.30	35.30	23.19	0.142	1.494
50	26.24	35.30	23.20	0.236	1.400
75	26.28	35.46	23.31	0.352	1.284
100	26.30	35.52	23.35	0.467	1.169
150	18.55	35.47	25.51	0.645	0.991
200	14.32	35.18	26.28	0.750	0.886
250	12.52	34.97	26.48	0.836	0.800
300	11.40	34.84	26.59	0.915	0.721
400	09.72	34.72	26.80	1.047	0.589
500	08.14	34.63	26.98	1.172	0.464
600	07.17	34.58	27.09	1.284	0.352
700	06.37	34.56	27.18	1.388	0.248
800	05.69	34.58	27.28	1.484	0.152
1000	04.50	34.81	27.60	1.636	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 33

M/V Hugh M. Smith: Cruise 11, 00°02'N, 150°00'W, September 27, 1951. Messenger time: first cast, 2029 GCT; second cast, 2120 GCT. Weather: 02, cloud coverage 4. Wind: 120°, 17 kt. Sea: 1-3 ft. Wire angle: first cast, 65°; second cast, 32°. Depth of water: no data

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.20	35.21	22.83	4.53	0.37
14	26.98	35.17	22.87	4.54	0.34
31	26.56	35.19	23.02	4.38	0.39
63	25.93	35.20	23.23	4.15	0.46
122	19.95 2/	35.28	25.01	3.29	1.07
233	26.16 2/	35.07	23.06	3.24	1.11
1/					

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	27.20	35.21	22.83		
10	27.03	35.17	22.86		
20	26.82	35.17	22.92		
30	26.56	35.19	23.02		
50	26.17	35.20	23.15		
75	25.70	35.20	23.30		
100	25.20	35.20	23.45		
150	19.87	35.26	25.28		
200	13.70	35.04	26.30		

1/ Values below 233 meters discarded. Suspect pretripping; depths uncertain.

2/ Suspected wrong break.

STATION 34

M/V Hugh M. Smith: Cruise 11, 01°02'N, 150°01'W, September 28, 1951. Messenger time: first cast, 0744 GCT; second cast, 0811 GCT; third cast, 0845 GCT. Weather: 02, cloud coverage not recorded. Wind: 090°, 16 kt. Sea: 1-3 ft. Wire angle: first cast, 57°; second cast, 57°; third cast, 64°. Depth of water: no data

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.30	35.14	22.74	4.59	0.32
09	27.36	35.16	22.74	4.53	0.29
19	27.36	35.17	22.75	4.59	0.29
38	27.33	35.16	22.76	4.55	0.26
70	26.62	35.22	23.03	4.49	0.39
118	25.05	35.12	23.44	4.03	0.61
167	15.30	34.73	25.60	2.55	1.25
215	12.74	34.74	26.26	2.48	1.51
256	12.16	34.87	26.48	0.86	2.05
309	11.58	34.80	26.53	0.68	2.12
415	09.46	34.68	26.81	1.38	2.19
1/					
2/					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	27.30	35.14	22.74		
10	27.36	35.16	22.74		
20	27.36	35.17	22.75		
30	27.36	35.16	22.74		
50	27.21	35.17	22.80		
75	26.60	35.22	23.03		
100	25.72	35.17	23.27		
150	18.25	34.76	25.05		
200	13.29	34.73	26.14		
250	12.32	34.85	26.43		
300	11.69	34.81	26.52		
400	09.69	34.69	26.78		

1/ Values below 415 meters discarded. Unreasonable chemical values suggest Nansen bottle leakage.

2/ Depths and temperatures uncertain, possibly due to exces-

STATION 35

M/V Hugh M. Smith: Cruise 11, 02°01'N, 149°53'W,
September 28, 1951. Messenger time: 1802 GCT.
Weather: 03, cloud coverage 4. Wind: 080°, 16 kt.
Sea: 1-3 ft. Wire angle: 40°. Depth of water: no data

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.40	34.93	22.54	4.51	0.43
08	27.44	34.94	22.55	4.50	
18	27.46	34.94	22.55	4.52	0.44
38	27.45	34.96	22.56	4.48	0.45
74	27.30	34.95	22.61	4.47	0.48
141	24.97	35.12	23.46	4.01	0.69
202	12.34	34.85	26.43	1.54	1.92
267	11.84	34.85	26.52	1.53	1.98
331	11.13	34.79	26.61	1.18	2.24
395	10.42	34.73	26.69	1.83	2.07
522	08.44	34.63	26.93	1.04	2.58
658	06.74	1/		1/	1/
817	05.32	34.70	27.42	1.76	2.28

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.40	34.93	22.54	0.000	1.800
10	27.44	34.94	22.55	0.053	1.747
20	27.46	34.94	22.55	0.106	1.694
30	27.45	34.95	22.56	0.159	1.641
50	27.42	34.96	22.57	0.265	1.535
75	27.30	34.95	22.61	0.398	1.402
100	26.90	35.19	22.91	0.527	1.274
150	22.30	34.93	24.10	0.749	1.051
200	12.42	34.85	26.41	0.889	0.911
250	11.98	34.86	26.50	0.977	0.829
300	11.48	34.82	26.56	1.050	0.750
400	10.37	34.73	26.70	1.201	0.599
500	08.72	34.64	26.90	1.337	0.464
600	07.40	34.60	27.07	1.455	0.345
700	06.32	34.62	27.23	1.558	0.242
800	05.48	34.69	27.40	1.646	0.155
1000	(04.04)	(34.55)	27.45	1.800	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 36

M/V *Hugh M. Smith*: Cruise 11, 03°00'N, 150°03'W, September 29, 1951. Messenger time: 0238 GCT. Weather: 02, cloud coverage 3. Wind: 090°, 16 kt. Sea: 1-3 ft. Wire angle: 42°. Depth of water: 2500 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.30	35.12	22.73	4.61	0.31
08	27.32	35.11	22.72	4.64	0.30
21	27.16	35.10	22.76	4.62	0.31
42	27.13	35.09	22.77	4.62	0.32
80	26.95	35.11	22.84	4.58	0.34
156	24.49	35.08	23.57	3.88	0.60
234	11.52	34.79	26.54	0.91	1.79
309	10.60	34.74	26.66	1.92	2.10
388	09.74	34.66	26.75	1.59	2.13
467	08.89	34.61	26.85	1.33	2.29
636	06.86	34.52	27.08	0.95	2.92
812	05.58	1/		1/	1/
996	04.66	34.57	27.39	1.17	2.61

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D 1000 - Δ D (dyn. m)
00	27.30	35.12	22.73	0.000	1.814
10	27.28	35.11	22.73	0.051	1.763
20	27.16	35.10	22.76	0.103	1.711
30	27.15	35.09	22.76	0.154	1.660
50	27.11	35.09	22.77	0.256	1.558
75	26.98	35.10	22.82	0.383	1.431
100	26.87	35.12	22.87	0.510	1.304
150	25.85	35.16	23.22	0.754	1.060
200	13.12	34.77	26.21	0.919	0.895
250	11.33	34.79	26.57	1.002	0.812
300	10.70	34.75	26.65	1.077	0.737
400	09.62	34.65	26.76	1.219	0.595
500	08.48	34.59	26.90	1.350	0.464
600	07.28	34.53	27.03	1.470	0.344
700	06.30	34.59	27.21	1.575	0.239
800	05.62	34.68	27.37	1.665	0.149
1000	04.62	34.57	27.40	1.814	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 37

M/V Hugh M. Smith: Cruise 11, 03°58'N, 150°00'W, September 29, 1951. Messenger time: 1117 GCT. Weather: 02, cloud coverage 1. Wind: 110°, 13 kt. Sea: 1-3 ft. Wire angle: 30°. Depth of water: 2700 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.20	35.04	22.71	4.54	0.38
09	27.19	35.04	22.71	4.53	0.44
23	27.19	35.05	22.72	4.55	0.41
47	27.12	35.09	22.77	4.55	0.40
92	26.71	35.14	22.94	4.42	0.61
180	17.15	34.70	25.27	2.73	1.09
267	09.98	34.58	26.65	2.27	2.00
360	09.15	34.62	26.82	1.63	2.18
451	08.57	34.61	26.90	1.66	2.30
542	07.77	34.58	27.00	1.09	2.81
725	06.20	34.51	27.16	1.34	2.88
914	05.10	34.66	27.42	2.40	2.05
1103	04.34	34.69	27.52	2.43	1.68

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.20	35.04	22.71	0.000	1.807
10	27.19	35.04	22.71	0.052	1.755
20	27.19	35.05	22.72	0.103	1.704
30	27.17	35.06	22.73	0.155	1.652
50	27.10	35.09	22.78	0.257	1.550
75	26.90	35.14	22.88	0.384	1.423
100	26.65	35.14	22.96	0.508	1.299
150	24.88	35.10	23.48	0.744	1.063
200	14.24	34.60	25.85	0.903	0.904
250	10.26	34.58	26.60	0.996	0.811
300	09.68	34.60	26.71	1.068	0.739
400	08.91	34.62	26.85	1.202	0.605
500	08.13	34.60	26.96	1.326	0.481
600	07.21	34.55	27.06	1.441	0.366
700	06.38	34.51	27.14	1.548	0.259
800	05.72	34.57	27.27	1.646	0.161
1000	04.60	34.68	27.49	1.807	0.000

STATION 38

M/V Hugh M. Smith: Cruise 11, 04°59'N, 149°56'W, September 29, 1951. Messenger time: 2005 GCT. Weather: 03, cloud coverage 8. Wind: 080°, 11 kt. Sea: 1-3 ft. Wire angle: 20°. Depth of water: 2600 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.20	35.00	22.37	4.47	0.06
09	28.10	34.98	22.37	4.39	0.08
23	28.08	34.98	22.38	4.43	0.06
51	27.76	35.10	22.57	4.53	0.14
102	26.46	35.16	23.03	4.31	0.33
206	13.38	34.58	26.01	1.85	1.50
309	09.29	34.63	26.80	1.70	2.03
417	08.54	34.59	26.89	1.41	2.24
522	07.94	34.54	26.94	1.03	2.47
625	07.07	34.54	27.07	0.85	2.69
830	05.56	34.50	27.23	0.84	2.76
1036	04.49	34.51	27.37	1.29	2.73
1242	03.74	34.51	27.44	1.07	2.66

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.20	35.00	22.37	0.000	1.855
10	28.10	34.98	22.37	0.055	1.800
20	28.08	34.98	22.38	0.110	1.745
30	28.01	35.00	22.41	0.164	1.691
50	27.76	35.10	22.57	0.272	1.583
75	27.28	35.14	22.75	0.403	1.452
100	26.49	35.16	23.02	0.528	1.327
150	25.09	35.11	23.42	0.764	1.091
200	13.89	34.59	25.91	0.931	0.924
250	10.72	34.62	26.55	1.023	0.832
300	09.41	34.63	26.78	1.095	0.760
400	08.67	34.61	26.88	1.224	0.631
500	08.10	34.55	26.93	1.348	0.507
600	07.28	34.54	27.04	1.466	0.389
700	06.46	34.52	27.14	1.574	0.281
800	05.73	34.50	27.21	1.674	0.181
1000	04.59	34.51	27.36	1.855	0.000

STATION 39

M/V Hugh M. Smith: Cruise 11, 05°56'N, 150°00'W, September 30, 1951. Messenger time: 0439 GCT. Weather: 02, cloud coverage 1. Wind: 070°, 14 kt. Sea: 1-3 ft. Wire angle: 10°. Depth of water: 2600 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.90	34.53	21.78	4.42	0.30
10	28.86	34.53	21.78	4.46	0.31
25	28.84	34.52	21.78	4.48	0.32
49	28.80	34.52	21.79	4.48	0.41
98	26.38	35.00	22.93	3.82	0.78
200	11.42	34.65	26.45	0.81	2.47
294	09.54	34.64	26.77	1.17	2.56
391	08.71	34.63	26.89	1.16	2.61
485	07.97	34.57	26.96	0.95	2.77
585	07.16	34.52	27.04	0.78	2.98
782	05.60	34.52	27.24	0.90	2.54
954	04.62	34.62	27.44	1.50	2.67
1136	03.98	34.55	27.45	1.51	3.02

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.90	34.53	21.78	0.000	1.766
10	28.86	34.53	21.78	0.060	1.706
20	28.85	34.52	21.78	0.121	1.645
30	28.83	34.52	21.78	0.181	1.585
50	28.80	34.52	21.79	0.302	1.464
75	28.02	34.74	22.21	0.449	1.317
100	26.30	35.00	22.96	0.581	1.185
150	17.50	34.61	25.12	0.777	0.989
200	11.42	34.65	26.45	0.891	0.875
250	10.24	34.64	26.65	0.968	0.798
300	09.50	34.64	26.76	1.038	0.728
400	08.61	34.62	26.90	1.167	0.599
500	07.81	34.56	26.97	1.288	0.478
600	07.01	34.51	27.05	1.402	0.364
700	06.20	34.52	27.17	1.508	0.258
800	05.49	34.53	27.27	1.604	0.162
1000	04.54	34.62	27.45	1.766	0.000

STATION 40

M/V Hugh M. Smith: Cruise 11, 06°51'N, 149°57'W, September 30, 1951. Messenger time: 1310 GCT. Weather: 20, cloud coverage not recorded. Wind: 060°, 18 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2600 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.80	34.39	21.68	4.34	0.32
11	28.86	34.42	21.70	4.48	0.36
23	28.86	34.40	21.68	4.48	0.35
48	28.87	34.44	21.71	4.51	0.34
95	22.38	34.83	24.00	4.10	0.51
190	11.10	34.64	26.50	0.72	2.45
276	09.58	34.66	26.78	0.98	2.59
370	08.93	34.61	26.84	1.21	2.55
458	08.24	34.60	26.94	1.12	2.73
553	07.43	34.54	27.02	0.79	2.94
738	05.60	34.50	27.23	1.22	3.06
923	04.84	34.54	27.35	1.34	2.57
1114	04.10	34.60	27.48	1.17	2.46

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.80	34.39	21.68	0.000	1.665
10	28.86	34.42	21.70	0.061	1.604
20	28.86	34.41	21.69	0.123	1.542
30	28.86	34.40	21.68	0.184	1.481
50	28.85	34.44	21.72	0.307	1.358
75	27.30	34.86	22.54	0.450	1.215
100	21.22	34.77	24.28	0.562	1.103
150	12.92	34.47	26.02	0.705	0.960
200	10.84	34.65	26.54	0.794	0.871
250	09.85	34.66	26.72	0.866	0.799
300	09.40	34.65	26.81	0.934	0.731
400	08.70	34.61	26.91	1.063	0.602
500	07.90	34.57	26.97	1.184	0.481
600	06.92	34.52	27.07	1.298	0.367
700	05.91	34.50	27.19	1.402	0.263
800	05.28	34.51	27.28	1.495	0.170
1000	04.64	34.55	27.38	1.665	0.000

STATION 41

M/V *Hugh M. Smith*: Cruise 11, 07°51'N, 149°57'W, September 30, 1951. Messenger time: 2229 GCT. Weather: 02, cloud coverage 5. Wind: 060°, 16 kt. Sea: 3-5 ft. Wire angle: 15°. Depth of water: 2900 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.60	34.34	21.72	4.52	0.36
11	28.58	34.34	21.73	4.55	0.40
25	28.54	34.33	21.73	4.56	0.39
54	27.09	34.90	22.64	4.51	0.46
107	12.98	34.41	25.96	1.59	2.18
212	10.46	34.67	26.63	0.64	2.71
316	09.57	34.67	26.79	0.53	2.76
420	08.72	34.59	26.86	0.71	2.78
520	07.62	34.54	26.99	0.64	3.19
622	06.51	34.52	27.13	0.95	3.14
826	05.22	34.52	27.29	0.73	3.19
1032	04.30	34.54	27.41	1.40	3.04
1230	03.61	34.55	27.49	0.89	2.97

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.60	34.34	21.72	0.000	1.554
10	28.58	34.34	21.73	0.061	1.493
20	28.56	34.33	21.73	0.122	1.432
30	28.50	34.35	21.76	0.183	1.371
50	27.72	34.77	22.33	0.299	1.255
75	23.73	34.86	23.64	0.421	1.133
100	15.40	34.48	25.50	0.506	1.048
150	11.41	34.60	26.41	0.602	0.952
200	10.59	34.67	26.61	0.681	0.873
250	10.13	34.68	26.70	0.753	0.801
300	09.70	34.68	26.77	0.822	0.732
400	08.90	34.60	26.84	0.954	0.600
500	07.82	34.55	26.97	1.078	0.476
600	06.72	34.52	27.10	1.190	0.364
700	05.90	34.52	27.21	1.291	0.263
800	05.33	34.52	27.28	1.384	0.170
1000	04.49	34.54	27.39	1.554	0.000

STATION 42

M/V Hugh M. Smith: Cruise 11, 08°57'N, 149°58'W, October 1, 1951. Messenger time: 0801 GCT. Weather: 50, cloud coverage not recorded. Wind: 060°, 16 kt. Sea: 3-5 ft. Wire angle: 10°. Depth of water: 2700 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.00	34.42	21.97		0.18
10	28.05	34.43	21.97	4.56	0.20
25	27.96	34.43	22.00	4.55	0.17
49	22.61	34.50	23.69	4.86	0.23
99	12.32	34.30	26.01	2.17	1.85
199	10.58	34.67	26.61	0.21	2.43
295	09.62	34.64	26.75	0.40	2.58
393	08.70	34.59	26.86	0.34	2.75
487	08.03	34.56	26.94	0.43	2.84
587	06.96	34.50	27.05	0.44	2.96
785	05.54	34.51	27.24	0.57	3.05
979	04.66	34.51	27.35	1.03	3.02
1179	03.92	34.54	27.45	1.00	2.84

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.00	34.42	21.97	0.000	1.468
10	28.05	34.43	21.97	0.059	1.409
20	28.01	34.43	21.98	0.117	1.351
30	26.95	34.67	22.51	0.174	1.294
50	22.61	34.50	23.69	0.270	1.198
75	15.55	34.32	25.34	0.356	1.112
100	12.31	34.30	26.01	0.414	1.054
150	11.20	34.65	26.49	0.505	0.963
200	10.56	34.67	26.62	0.582	0.886
250	10.05	34.66	26.70	0.654	0.814
300	09.59	34.64	26.76	0.723	0.745
400	08.65	34.59	26.86	0.854	0.614
500	07.90	34.55	26.96	0.977	0.491
600	06.84	34.50	27.07	1.091	0.377
700	06.03	34.50	27.17	1.196	0.272
800	05.47	34.51	27.25	1.292	0.176
1000	04.60	34.51	27.36	1.468	0.000

STATION 43

M/V Hugh M. Smith: Cruise 11, 10°00'N, 150°13'W, October 1, 1951. Messenger time: 1636 GCT. Weather: 02, cloud coverage 3. Wind: 050°, 18 kt. Sea: 3-5 ft. Wire angle: 20°. Depth of water: 2700 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.80	34.16	21.83	4.56	0.24
10	27.86	34.14	21.81	4.56	0.23
25	27.64	34.46	22.13	4.68	0.26
47	23.26	34.54	23.53	4.83	0.30
94	12.37	34.35	26.03	2.11	1.92
188	10.68	34.69	26.61	0.26	2.58
275	09.72	34.67	26.76	0.57	2.62
367	08.84	34.60	26.85	0.46	2.72
454	08.14	34.57	26.94	1.07	2.87
546	07.21	34.52	27.03	0.89	2.87
730	05.80	34.51	27.21	0.73	3.04
914	04.88	34.52	27.33	0.89	2.70
1110	04.14	34.59	27.47	0.78	2.34

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.80	34.16	21.83	0.000	1.443
10	27.86	34.14	21.81	0.060	1.383
20	27.72	34.40	22.06	0.119	1.324
30	27.20	34.66	22.42	0.176	1.267
50	22.30	34.51	23.64	0.272	1.171
75	14.15	34.35	25.67	0.355	1.088
100	12.17	34.37	26.09	0.408	1.035
150	11.18	34.68	26.51	0.496	0.947
200	10.51	34.69	26.64	0.572	0.871
250	09.97	34.68	26.73	0.643	0.800
300	09.46	34.65	26.79	0.710	0.733
400	08.61	34.59	26.88	0.839	0.604
500	07.68	34.54	26.98	0.962	0.481
600	06.72	34.51	27.09	1.074	0.369
700	05.98	34.51	27.19	1.177	0.266
800	05.42	34.51	27.26	1.272	0.171
1000	04.49	34.55	27.40	1.443	0.000

STATION 44

M/V *Hugh M. Smith*: Cruise 11, 10°58'N, 150°02'W, October 2, 1951. Messenger time: 0120 GCT. Weather: 02, cloud coverage 6. Wind: 060°, 16 kt. Sea: 3-5 ft. Wire angle: 33°. Depth of water: 2800 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	28.00	34.03	21.68	4.49	0.06
08	28.03	34.03	21.68	4.42	0.07
20	27.98	34.03	21.69	4.49	0.06
43	26.76	34.68	22.58	4.70	0.12
85	16.70	34.36	25.11	3.57	0.81
163	11.42	34.71	26.49	0.13	3.35
240	10.40	34.68	26.65	0.19	2.44
319	09.60	34.65	26.76	0.18	2.55
397	08.90	34.61	26.85	0.22	2.65
474	07.96	34.54	26.94	0.23	2.79
627	06.54	1/		1/	1/
787	05.36	34.47	27.23	0.59	2.44
977	04.53	34.51	27.36	1.08	2.80

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.00	34.03	21.68	0.000	1.515
10	28.00	34.03	21.69	0.061	1.454
20	27.98	34.03	21.69	0.123	1.392
30	27.94	34.12	21.77	0.184	1.331
50	25.30	34.65	23.01	0.293	1.222
75	19.22	34.41	24.53	0.397	1.118
100	14.36	34.35	25.63	0.468	1.047
150	11.72	34.63	26.37	0.571	0.944
200	10.87	34.70	26.59	0.649	0.866
250	10.28	34.67	26.66	0.723	0.792
300	09.81	34.66	26.74	0.793	0.722
400	08.87	34.61	26.85	0.926	0.589
500	07.69	34.52	26.96	1.049	0.466
600	06.78	34.48	27.06	1.164	0.351
700	06.00	34.47	27.16	1.244	0.271
800	05.28	34.47	27.24	1.341	0.174
1000	04.50	34.51	27.37	1.515	0.000

1/ Unreasonable chemical values suggest Nansen bottle leakage.

STATION 45

M/V Hugh M. Smith: Cruise 11, 11°59'N, 150°03'W, October 2, 1951. Messenger time: 1010 GCT. Weather: 02, cloud coverage not recorded. Wind: 070°, 16 kt. Sea: 1-3 ft. Wire angle: 30°. Depth of water: 2800 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.70	34.42	22.08	4.58	0.17
08	27.70	34.42	22.08	4.74	0.19
22	27.70	34.41	22.07	4.61	0.24
46	26.20	34.61	22.70	4.80	0.33
90	20.40	34.70	24.45	4.87	0.25
176	10.91	34.24	26.22	2.52	2.28
260	10.17	34.59	26.62	0.31	2.59
349	09.00	34.54	26.78	0.41	2.59
436	08.20	34.53	26.89	0.57	2.74
525	07.29	34.51	27.01	0.63	2.79
707	05.93	34.50	27.19	0.39	3.02
894	04.76	34.52	27.35	0.73	3.05
1078	04.01	34.51	27.42	0.55	2.84

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	Δ D_{1000} - Δ D (dyn. m)
00	27.70	34.42	22.08	0.000	1.597
10	27.70	34.42	22.08	0.058	1.539
20	27.70	34.41	22.07	0.115	1.482
30	27.65	34.43	22.10	0.173	1.424
50	25.28	34.65	23.01	0.280	1.317
75	21.70	34.70	24.09	0.390	1.207
100	19.80	34.68	24.59	0.480	1.117
150	13.10	34.32	25.87	0.619	0.978
200	10.45	34.51	26.51	0.712	0.885
250	10.22	34.58	26.61	0.789	0.808
300	09.65	34.56	26.69	0.862	0.735
400	08.53	34.54	26.85	0.997	0.600
500	07.53	34.51	26.98	1.120	0.477
600	06.73	34.50	27.09	1.232	0.365
700	05.99	34.50	27.18	1.335	0.262
800	05.30	34.51	27.28	1.430	0.167
1000	04.20	34.51	27.40	1.597	0.000

STATION 46

M/V *Hugh M. Smith*: Cruise 11, 13°00'N, 149°56'W, October 2, 1951. Messenger time: 1835 GCT. Weather: 02, cloud coverage 3. Wind: 060°, 16 kt. Sea: 1-3 ft. Wire angle: 15°. Depth of water: 2900 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.30	34.70	22.41	4.51	0.21
10	27.31	34.71	22.42	4.46	0.31
24	27.31	34.72	22.43	4.45	0.20
53	26.29	34.76	22.78	4.61	0.18
106	20.26	34.85	24.60	4.71	0.34
209	10.90	34.44	26.38	1.00	2.34
311	09.36	34.55	26.73	0.35	2.61
418	08.26	34.51	26.87	0.50	2.67
523	07.24	34.47	26.99	0.43	2.80
629	06.37	34.47	27.11		2.93
836	05.14	34.46	27.25	0.82	2.90
1044	04.26	34.51	27.39	1.05	2.82
1241	03.65	34.51	27.45	1.37	2.75

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.30	34.70	22.41	0.000	1.639
10	27.31	34.71	22.42	0.054	1.585
20	27.31	34.71	22.42	0.109	1.530
30	27.30	34.73	22.44	0.163	1.476
50	26.40	34.76	22.75	0.268	1.371
75	23.00	34.87	23.36	0.385	1.254
100	20.50	34.86	24.54	0.479	1.160
150	15.88	34.64	25.52	0.629	1.010
200	11.10	34.44	26.34	0.736	0.903
250	10.21	34.51	26.55	0.818	0.821
300	09.48	34.56	26.72	0.892	0.747
400	08.44	34.52	26.84	1.026	0.613
500	07.43	34.48	26.96	1.149	0.490
600	06.55	34.47	27.09	1.262	0.377
700	05.86	34.46	27.17	1.365	0.274
800	05.32	34.46	27.23	1.463	0.176
1000	04.42	34.50	27.37	1.639	0.000

STATION 47

M/V Hugh M. Smith: Cruise 11, 14°01'N, 150°03'W, October 3, 1951. Messenger time: 0302 GCT. Weather: 80, cloud coverage 8. Wind: 080°, 18 kt. Sea: 3-5 ft. Wire angle: 25°. Depth of water: 2900 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.20	34.48	22.28	4.62	0.27
09	27.24	34.51	22.29	4.63	0.27
24	27.18	34.51	22.31	4.63	0.25
51	26.59	34.93	22.82	4.71	0.26
100	22.02	34.88	24.14	5.18	0.23
198	11.31	34.13	26.06	4.04	1.16
293	09.76	34.51	26.63	0.72	2.57
394	08.65	34.53	26.82	0.50	2.66
493	07.64	34.48	26.94	0.68	2.77
593	06.66	34.45	27.05	0.76	2.90
788	05.44	34.46	27.22	0.56	3.05
987	04.52	34.51	27.36	1.67	2.15
1184	03.76	34.50	27.43	1.59	2.22

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	27.20	34.48	22.28	0.000	1.716
10	27.24	34.51	22.29	0.056	1.660
20	27.20	34.51	22.31	0.111	1.605
30	27.10	34.53	22.36	0.166	1.550
50	26.59	34.94	22.82	0.272	1.444
75	24.78	34.93	23.38	0.392	1.324
100	22.02	34.88	24.14	0.497	1.219
150	17.90	34.60	25.01	0.668	1.048
200	11.21	34.14	26.09	0.792	0.924
250	10.22	34.39	26.46	0.882	0.834
300	09.68	34.52	26.65	0.959	0.757
400	08.60	34.53	26.83	1.097	0.619
500	07.57	34.48	26.95	1.222	0.494
600	06.60	34.45	27.05	1.337	0.379
700	05.89	34.45	27.15	1.442	0.274
800	05.38	34.47	27.23	1.540	0.176
1000	04.50	34.51	27.36	1.716	0.000

STATION 48

M/V Hugh M. Smith: Cruise 11, 15°02'N, 150°01'W, October 3, 1951. Messenger time: 1110 GCT. Weather: 02, cloud coverage 3. Wind: 080°, 19 kt. Sea: 3-5 ft. Wire angle: 16°. Depth of water: 3000 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	26.70	1/		4.65	0.06
09	26.67	34.80	22.70	4.65	0.06
24	26.64	34.81	22.71	4.65	0.04
52	26.61	34.81	22.72	4.63	0.10
105	21.86	34.89	24.19	5.66	0.05
207	12.52	34.19	25.88	3.07	1.17
309	09.12	34.32	26.59	1.14	2.27
417	08.08	34.43	26.83	0.39	2.60
518	07.00	34.40	26.97	0.60	2.69
621	06.22	34.44	27.10	0.71	2.76
821	05.23	34.44	27.23	0.69	2.89
1023	04.40	34.45	27.33	1.00	2.88
1220	03.72	34.47	27.41	1.53	1.96

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.70	34.80	22.70	0.000	1.762
10	26.67	34.80	22.69	0.052	1.711
20	26.65	34.81	22.71	0.103	1.660
30	26.63	34.81	22.71	0.155	1.608
50	26.61	34.81	22.72	0.258	1.505
75	23.73	34.88	23.65	0.377	1.386
100	22.37	34.89	24.05	0.479	1.284
150	20.10	34.78	24.59	0.660	1.103
200	15.12	34.35	25.46	0.810	0.953
250	09.96	34.23	26.38	0.911	0.852
300	09.23	34.31	26.56	0.992	0.771
400	08.25	34.42	26.80	1.135	0.628
500	07.17	34.40	26.95	1.261	0.502
600	06.34	34.43	27.08	1.375	0.388
700	05.80	34.44	27.16	1.478	0.285
800	05.35	34.44	27.21	1.577	0.186
1000	04.72	34.44	27.29	1.763	0.000

1/ Salinity sample bottle broken.

STATION 49

M/V Hugh M. Smith: Cruise 11, 17°00'N, 150°42'W, October 4, 1951. Messenger time: 0215 GCT. Weather: 02, cloud coverage 3. Wind: 050°, 19 kt. Sea: 1-3 ft. Wire angle: 28°. Depth of water: 2900 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	25.80	34.82	22.99	4.76	0.15
09	25.76	34.80	22.98	4.78	0.18
22	25.62	34.81	23.03	4.76	0.22
48	25.60	34.86	23.07	4.78	0.21
95	22.68	34.77	23.87	5.16	0.27
186	17.48	34.53	25.06	4.24	0.59
275	11.18	34.41	26.30	1.41	2.25
368	09.68	34.49 1/	26.63	0.31	2.63
459	08.04	34.36 1/	26.79	0.57	2.66
553	07.18	34.41	26.95	0.66	2.75
738	05.76	34.40	27.13	0.67	2.86
932	04.76	34.44	27.28	0.86	2.88
1124	04.06	34.45	27.36	1.10	2.67

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.80	34.82	22.99	0.000	1.836
10	25.75	34.80	22.98	0.049	1.787
20	25.65	34.81	23.02	0.098	1.738
30	25.62	34.83	23.04	0.146	1.690
50	25.60	34.86	23.07	0.243	1.593
75	25.43	34.87	23.13	0.363	1.473
100	22.48	34.76	23.92	0.472	1.364
150	20.57	34.68	24.38	0.663	1.173
200	15.98	34.47	25.36	0.820	1.016
250	11.75	34.41	26.20	0.935	0.901
300	10.77	34.43	26.39	1.024	0.812
400	09.09	34.45	26.69	1.180	0.656
500	07.61	34.39	26.87	1.316	0.520
600	06.80	34.41	27.00	1.437	0.399
700	06.05	34.40	27.10	1.548	0.288
800	05.37	34.41	27.19	1.651	0.185
1000	04.50	34.44	27.31	1.836	0.000

1/ Doubtful.

STATION 50

M/V Hugh M. Smith: Cruise 11, 19°00'N, 151°19'W, October 4, 1951. Messenger time: 1717 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 17 kt. Sea: 1-3 ft. Wire angle: 23°. Depth of water: 2900 f.

OBSERVED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	25.50	34.91	23.14	4.75	0.18
09	25.50	34.90	23.13	4.77	0.21
23	25.52	34.91	23.14	4.77	0.25
51	25.51	34.93	23.15	4.77	0.17
101	22.15	35.07	24.25	5.07	0.15
197	17.49	34.69	25.18	4.33	0.45
292	10.50	34.13	26.21	3.22	1.56
393	08.30	34.23	26.64	1.34	2.45
493	07.16	34.29	26.86	0.71	2.76
594	06.64	34.37	26.99	0.62	2.88
794	05.39	34.39	27.17	0.86	3.02
999	04.50	34.51	27.36	1.85	1.84
1198	03.86	34.51	27.43	2.98	1.19

INTERPOLATED AND CALCULATED					
DEPTH (m)	T (°C)	S (°/oo)	σ t (gm/l)	Δ D (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	25.50	34.91	23.14	0.000	1.815
10	25.50	34.90	23.13	0.047	1.768
20	25.51	34.91	23.14	0.095	1.720
30	25.51	34.92	23.14	0.142	1.673
50	25.51	34.93	23.15	0.237	1.578
75	23.61	35.04	23.81	0.349	1.466
100	22.16	35.07	24.25	0.447	1.368
150	19.58	34.89	24.80	0.620	1.195
200	17.27	34.67	25.22	0.771	1.044
250	12.55	34.19	25.88	0.897	0.918
300	10.28	34.14	26.25	0.997	0.818
400	08.21	34.26	26.68	1.162	0.653
500	07.11	34.30	26.88	1.297	0.518
600	06.60	34.38	27.01	1.418	0.397
700	06.00	34.38	27.09	1.529	0.286
800	05.35	34.39	27.17	1.633	0.182
1000	04.50	34.52	27.37	1.815	0.000

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orial Undercurrent in Pacific Ocean
led by New Methods

end Cromwell, R. B. Montgomery,[1]
D. Stroup

Oceanic Fishery Investigations,
b and Wildlife Service, Honolulu;
University, Providence, R.I.;
ific Oceanic Fishery Investigations,
b and Wildlife Service, Honolulu

ations of an eastward current at the equator
1 the westward South Equatorial Current came
lly from the drift of long-line fishing gear in
m vessels of the Pacific Oceanic Fishery In-
tions of the U.S. Fish and Wildlife Service.
observation of drifting objects, or "drags,"
he Service's research vessel *Hugh M. Smith*
Aug. 1952 proved the existence of this east-
urrent in the central Pacific near the equator
lower part of the surface layer and upper
line.

surface current at three stations was observed
owing a surface drag continuously for several
nd determining its movement by celestial navi-
. On 12 of the 18 days devoted to following the
drag, deep drags with identifying surface
vere released. The velocity of the deep drag was
ed relative to the motion of the surface drag
owing the identifying float with the vessel and
g the surface drag by radar up to ranges of 5
ctor subtraction then gives the deep drag's true
y, which can be used to make a close estimate
velocity of the deep current.

surface drag (Fig. 1) consisted of two 150 by
panels of fine-mesh netting joined end to end
yed to locate the top of the mesh 2 ft below
a surface. The use of netting combined large
resistance with ease of handling and stowage. A pole carrying a radar target and one carrying a flag and light were attached to the downwind end of the nets.

The deep drags (Fig. 2) were similar to a common form of sea anchor. Each consisted of a light muslin cone attached to an aluminum alloy hoop weighted at the bottom and buoyed at the top so that it would remain upright. Piano wire of diameter 0.72 mm joined the deep drag unit to two streamlined floats, one at the sea surface and the other slightly submerged. The drags used were 3 and 4 m in hoop diameter, so large that retrieval was impossible and a drag could be used only once.

Wind resistance of the poles prevented perfectly free movement of the surface drag with the current, and water resistance of the wire and floats similarly affected the deep drags. Corrections to reduce the drag velocities to current velocities are being determined, and a complete account of the data and results is being prepared for later publication. However, the submerged countercurrent can be described now in terms that will not be altered by these corrections.

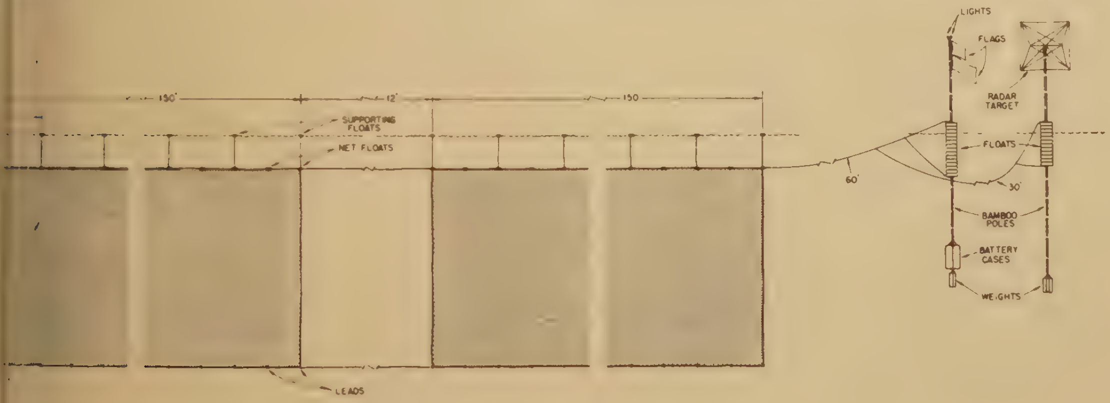

Fig. 1. Drag used to measure the surface current.

The 12 observations of the deep current were made near 150°W from 2°54′S to 7°05′N. The first, at 2°54′S at a depth of 200 ft, gave a northwesterly current of a little less than half a knot.

The following eight observations were in almost daily succession during the second drag station. The first four of these from 0°14′N to 1°31′N at depths in the lower part of the surface layer and upper thermocline indicated currents with easterly components. At the first of them, at 0°14′N, the surface current was nearly 1 knot north, while the deep drag indicated an east current stronger than 1 knot. The last four observations on this station, from 1°50′N to 2°43′N, revealed zonal flow directed west.

The final three drags were used at the third drag station, near 7°N in the Equatorial Countercurrent, where the current was easterly by both surface and deep drags.

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arch sponsored by Office of Naval Research.

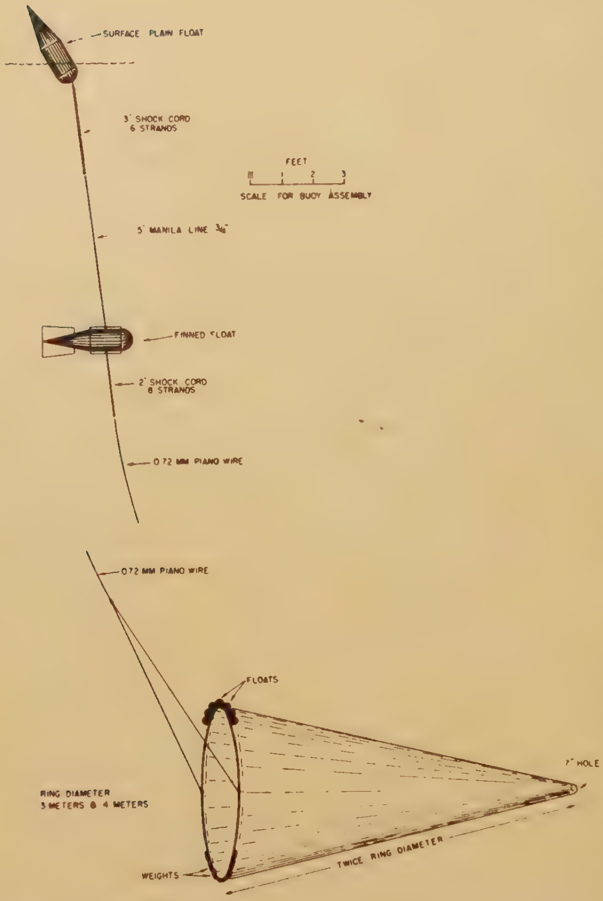
SURFACE PLAIN FLOAT
3' SHOCK CORD 6 STRANDS
FEET
0 1 2 3
SCALE FOR BUOY ASSEMBLY
5' MANILA LINE 3/8"
FINNED FLOAT
2' SHOCK CORD 6 STRANDS
0.72 MM PIANO WIRE
0.72 MM PIANO WIRE
FLOATS
7" HOLE
RING DIAMETER 3 METERS & 4 METERS
WEIGHTS
TWICE RING DIAMETER

Fig. 2. Deep drag and buoy assembly used to measure the deep current.

The submerged east current was, thus, observed in a narrow zone near the equator, the speed of the axis exceeding 1 knot. It was separated from the Equatorial Countercurrent by water with a westward velocity component.

As mentioned in the opening paragraph
tions of the drift of long-line fishing gear
cated the presence of the submerged current.
line is a system of cotton lines suspended fr
and floated freely in the water, the main ma
lying, in these trials, in the lower part of th
layer. This gear has been set very near the
number of times on various longitudes and,
occasions, has moved eastward in spite of
southeast trade winds and seas at the surf
gesting that the submerged current is preva
the equator in the central Pacific. Whether
current prevails in the eastern and wester
and in the Atlantic remains to be determine
ther study.

In part, the dynamics of the current se
The surface layer of warm water deepens
so that throughout this layer there is an eastw
ponent of pressure-gradient force (*1*). B
depth of influence of the southeast trade win
flows east in response to the pressure gradie
considerations do not explain the narrowne
current.

On this basis, the countercurrent at the equ
be expected to extend up to the sea surface
wind stress is released or sufficiently diminish
an occurrence could explain reports of eastw
of vessels close to the equator in the easter
and the Atlantic (*2*).

The countercurrent at the equator may, th
sionally be observed at the surface but is ap
more prevalent in the lower part of the surf
and in the thermocline. For this reason t
"Equatorial Undercurrent" is proposed.

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Received March 8, 1954.

VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

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Special Scientific Report: Fisheries No. 118

WASHINGTON: MARCH 1954

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VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

One of the major projects in the research program of the Pacific Oceanic Fishery Investigations of the Fish and Wildlife Service is to obtain information on the relative or potential productivity of different areas of the tropical and subtropical Pacific. As indexes to productivity we have considered the oceanic circulation, the concentration of a chemical nutrient (inorganic phosphate), the amount of dissolved oxygen, and the abundance of zooplankton.

The purpose of this report is to present the results of our zooplankton sampling in waters adjacent to the main or windward islands of the Hawaiian archipelago. We shall consider how the abundance of zooplankton varied geographically and in time during the period of study and to what extent these variations were related to hydrographic conditions. The data contribute information on vertical distribution and diurnal variation in zooplankton abundance and indicate differences in relative productivity between the Hawaiian area and other regions of the central Pacific.

Zooplankton is essential fish food. It is important in the food of juvenile tunas and also occurs in wide variety in the food of adult tunas (Reintjes and King 1953). The bulk of the zooplankton, however, reaches the tunas -- the group of fish presently under study by these investigations -- through the intermediary forage organisms, such as squid, shrimp, and small fish. The standing crop of zooplankton is rather easily measured in quantitative fashion and, we believe, is a reliable index to available food.

Although the primary aim of our plankton sampling was to obtain information on the zooplankton population, a secondary objective was to collect tuna eggs and larvae for use in the study of the spawning habits of tuna[1]. Sampling gear and procedures, therefore, were utilized which would contribute toward both objectives.

These collections constitute the first comprehensive survey of zooplankton abundance in the offshore waters of the Hawaiian Islands. Sampling of the offshore waters heretofore was limited to occasional hauls made by the various oceanographic expeditions crossing the Pacific. In 1875 the Challenger made surface hauls at a few stations close to the islands (Murray 1895). In 1902 the U. S. Fisheries Steamer Albatross occupied a number of stations in the Hawaiian area, at which surface plankton hauls were made (Wilson 1950). When the Carnegie visited the Islands in 1929,

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1/ This will be the subject of a separate report by other staff members of POFI.

quantitative hauls, both vertical and horizontal, were carried out and while the resulting data are difficult to compare with our own, they do provide comparisons of plankton volumes and dry weights between Hawaii and other regions visited on the cruise (Graham 1941, Wilson 1942).

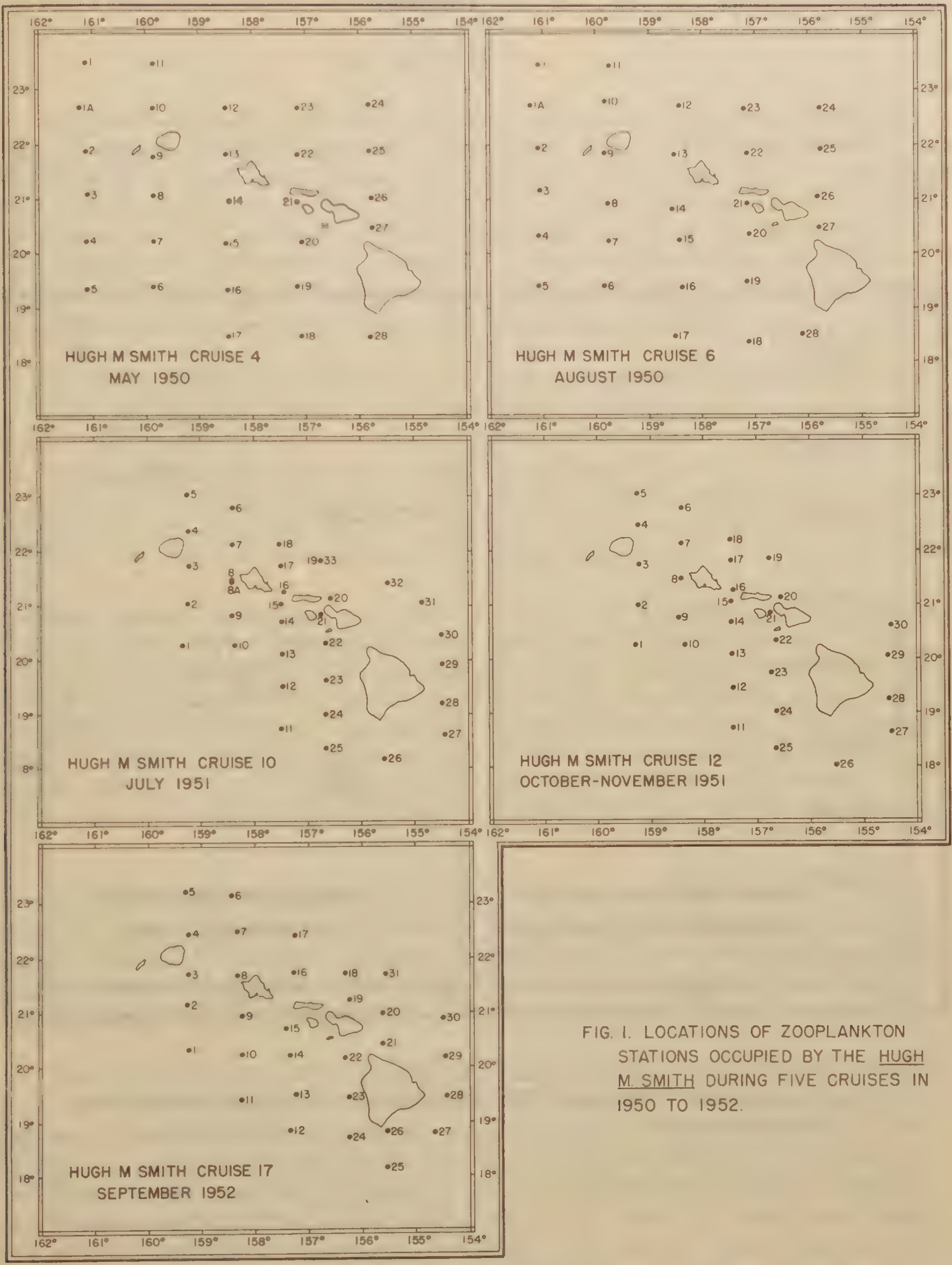
The inshore environment has received more recent attention. Edmondson (1937) did quantitative sampling in the shore waters of Oahu at a number of stations visited repeatedly during the year September 1931 to September 1932. He concluded that the copepods were an important food item in the reef and bay habitats, since he found the most luxuriant growth of coral and other sessile organisms as well as the largest numbers of plankton-feeding fishes in areas of greatest abundance of free-swimming copepods. The University of Hawaii and the Division of Fish and Game of the Territory of Hawaii have in recent years made an intensive study of the early life history of the nehu, one of the important tuna bait fishes occurring in the Islands. A large number of quantitative plankton samples, obtained from the inshore waters of Oahu, have been examined for the eggs and larvae of the fish under investigation (Tester 1951). These collections have not as yet been analyzed for other plankton constituents, but they should provide suitable material for a study of variations in plankton composition and abundance in the inshore waters and for comparison with the available data from the offshore environment.

We wish to express our appreciation to fellow staff members of POFI and the officers and crews of the Hugh M. Smith and the John R. Manning for their assistance in obtaining the plankton collections on which this report is based. We are indebted to O. E. Sette, Director of the Pacific Oceanic Fishery Investigations, for his many helpful suggestions during the examination of the data and the preparation of the report. The hydrographic data employed in this study were collected and processed under the supervision of Thomas S. Austin and Townsend Cromwell. Mr. Tamotsu Nakata prepared the illustrations.

SOURCE OF MATERIAL

During the years 1950, 1951, and 1952, POFI vessels collected zooplankton on seven cruises in Hawaiian waters; 365 meter-net hauls were obtained at 204 stations by the U. S. Fish and Wildlife Service vessels Hugh M. Smith, on cruises 4, 6, 10, 12, and 17, and John R. Manning, on cruises 8 and 9. The approximate locations of the stations are shown in figures 1 and 2. More exact positions, together with dates, depths of hauling, and other pertinent data are given in tables 16 through 22 in the appendix. The time of hauling, as given in these seven tables, is local civil time for the Hawaiian area (Greenwich time ≠ 10 hours).

The five cruises of the Hugh M. Smith provide synoptic observations over the area from the island of Kauai on the west to the island of Hawaii on the east and adjacent waters to about 100 miles offshore in a north-south direction. On Cruise 8 of the John R. Manning, a line of stations west of Oahu was visited weekly for four successive weeks. Cruise 9 of the Manning was conducted in waters adjacent to Oahu for the purpose of measuring the variance among repeated hauls at the same station and other short-term variations in zooplankton abundance.



HUGH M SMITH CRUISE 4
MAY 1950

HUGH M SMITH CRUISE 6
AUGUST 1950

HUGH M SMITH CRUISE 10
JULY 1951

HUGH M SMITH CRUISE 12
OCTOBER-NOVEMBER 1951

HUGH M SMITH CRUISE 17
SEPTEMBER 1952

162°
161°
160°
159°
158°
157°
156°
155°
154°
23°
22°
21°
20°
19°
18°
1
1A
2
3
4
5
6
7
8
8A
9
10
11
12
13
14
15
16
17
18
19
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FIG. I. LOCATIONS OF ZOOPLANKTON STATIONS OCCUPIED BY THE HUGH M. SMITH DURING FIVE CRUISES IN 1950 TO 1952.

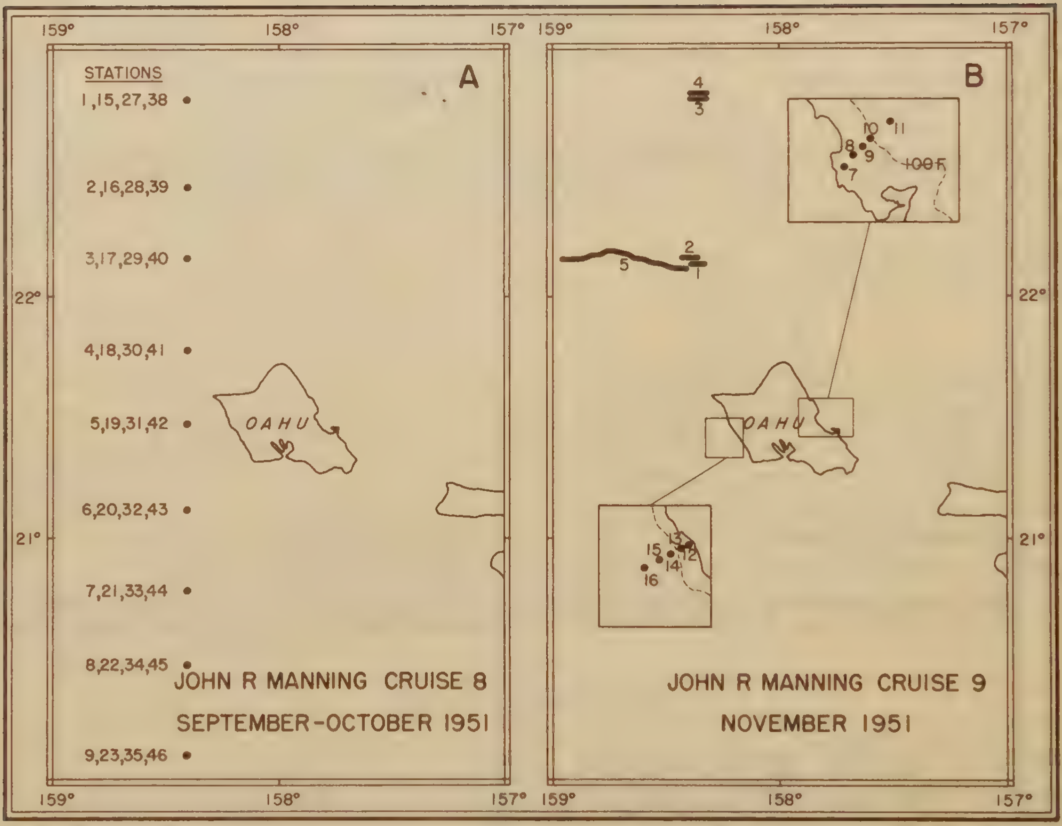
STATIONS
1,15,27,38
2,16,28,39
3,17,29,40
4,18,30,41
5,19,31,42
6,20,32,43
7,21,33,44
8,22,34,45
9,23,35,46
A
B
OAHU
JOHN R MANNING CRUISE 8
SEPTEMBER-OCTOBER 1951
JOHN R MANNING CRUISE 9
NOVEMBER 1951
159°
158°
157°
22°
21°
1
2
3
4
5
7
8
9
10
11
12
13
14
15
16
100 F.

FIG. 2. LOCATIONS OF ZOOPLANKTON STATIONS OCCUPIED BY THE JOHN R. MANNING ON TWO CRUISES IN 1951.

METHODS

In the Field

All collections reported on here were taken with nets of one type, i.e., 1-meter (mouth diameter) nets with body (front and middle sections) of 30XXX silk grit gauze (apertures 0.65 x 0.65 mm.), rear section and bag of 56XXX silk grit gauze (apertures 0.31 x 0.31 mm.). The 30XXX mesh makes up about 97 percent of the straining surface of the net, and the 56XXX mesh about 3 percent. Details of the construction of the net and the method of hauling have been described in a previous report (King and Demond 1953).

In this study two general types of hauls were employed: horizontal, with three nets towed simultaneously; and oblique, using a single net. Horizontal hauls of about 1 hour's duration, with sampling at three levels, were carried out on *Smith* cruises 4 and 6. Oblique hauls of about 30 minutes' duration to a depth of 200 meters were used on *Smith* cruises 10, 12, and 17 and *Manning* cruise 8; oblique hauls to *200, 300*, and 500 meters were used on *Manning* cruise 9.

The amount of water strained during each haul was estimated by measuring the flow past a current meter suspended in the mouth of the net and computing the total volume, assuming that the flow rate was uniform throughout the mouth of the net. The depth of the net during hauling was estimated by measuring at 2-minute intervals the angle of the towing wire and the length of wire out and making the appropriate calculation, assuming the towing wire to represent a straight line in the water. A 75 or 100-pound streamlined weight was attached to the end of the towing wire.

At the end of each haul the net was washed down thoroughly, concentrating the catch in the plankton sock or bag. The collection was then transferred to a 1-quart jar and sufficient formalin added to approximate a 10-percent solution. The formalin was neutralized with borax and a completed label was placed in the jar.

That this method of hauling is capable of producing repeatable results is demonstrated by a test of the experimental or sampling error among pairs of consecutive 200-meter oblique hauls made on cruise 9 of the *Manning*. A comparison of 16 pairs of replicate samples (following *Snedecor 1946*, p. 44) having a mean of 27.0 cc./1000 m.^{3}, gave a mean sample difference of 0.67 cc./1000 m.^{3}, which by the "t" test was shown to be not significantly different ($P > 0.4$) from zero. The standard deviation of the differences was 2.07, indicating that the two members of a pair of replicate hauls would be within 8.28 cc./1000 m.^{3} in 95 percent of the instances.

In the Laboratory

The collections received the following treatment in the laboratory:

(1) All fish eggs and larvae were removed from samples taken on Smith cruises 4 and 6. These amounted to a negligible fraction of the sample and were omitted from the volume measurements. For the other cruises the fish eggs and larvae were not removed from the collections.

(2) All organisms whose longest dimension was greater than 5 cm. were removed from the sample. The kind of organism removed and its displacement volume were recorded. As such organisms occurred infrequently, they are omitted from this analysis.

(3) All organisms whose longest dimension was between 2 and 5 cm. were next removed from the sample, identified as nearly as possible, and their displacement volume was measured.

(4) The remainder of the sample, those organisms measuring less than 2 cm. in their longest dimension and constituting the bulk of the sample, was examined under a binocular dissecting microscope and its general composition was noted. The displacement volume of this fraction was then determined after any artifacts, such as refuse from the ship, had been removed. This portion of the sample was not further subdivided.

In measuring the displacement volume, the plankton was poured into a draining sock of 56XXX grit gauze to filter off the preserving liquid. The drained plankton was then placed in a graduated cylinder of approximate size (usually of 50 or 100 ml. capacity). By means of a burette a known volume of water was added to the drained plankton. The difference between the volume of the plankton plus the added liquid and the volume of liquid alone was recorded as the displacement or net wet volume of that portion of the plankton sample.

For an estimate of the amount of zooplankton in each sample that was potentially fish food of significant nutritional value, the displacement volumes of the following were used:

(1) The entire remaining fraction of the sample after the larger organisms, 2 cm. or greater in their longest dimension, had been removed.

Ordinarily this portion of the sample was composed primarily of crustaceans and chaetognaths with a small percentage by number and volume of "watery" organisms of low food value, such as jellyfish and salps. As stated earlier, this portion of the sample was examined under the microscope and classified as to its make-up, whether of average (mixed) composition, composed primarily of a swarm of one organism, or containing an unusual amount of nonnutritious forms.

(2) All annelids, crustaceans, cephalopods, and fish in the 2 to 5 cm. size category.

The following organisms in the 2 to 5 cm. category were not included as food: siphonophores, medusae, ctenophores, heteropods[2], and tunicates.

The sum of items (1) and (2) provided a single volume measurement for each sample which we accepted as the best available estimate of the amount of zooplankton -- as food -- present at that time and place and subject to capture by the gear employed.

VERTICAL AND DIURNAL VARIATIONS

The collections resulting from cruises 4 and 6 of the *Hugh M. Smith* provide information of interest on the vertical distribution of zooplankton. The chief purpose of these two cruises was to investigate the time and extent of tuna spawning in Hawaiian waters. A sampling plan to examine horizontal and vertical variations in the abundance of tuna eggs and larvae was carried out at each station, with meter-net hauls being made simultaneously at three levels: 0, 50, and 150 meters; 0, 100, and 200 meters; or 0, 150, and 500 meters. There was no means of closing the nets while they were being lowered and raised, but the percentage of towing time during this phase of the haul was small and is not likely to have affected greatly the results. It was not possible to hold the ship's speed constant throughout the haul nor to change the spacing of the nets on the towing wire once the haul had started. Therefore the nets were not always at the intended depth. We believe, however, from calculations based on wire angle and meters of wire out that the actual towing depth ordinarily did not vary by more than ± 20 percent of the desired depth.

The data were classified into day, night, and twilight hauls on the criteria of times of sunrise, sunset, and the beginning and end of twilight periods as defined by the American Nautical Almanac. Averages were calculated for zooplankton volumes obtained at each haul level and the day collections were compared with the night collections. The twilight hauls were few in number and were omitted from the comparison. The results show (fig. 3) that for both cruises the greatest average volume of zooplankton occurred at the 50-meter level in both the day and the night hauls. It is obvious that the increase in the night over the day hauls, which is shown at all sample levels, could not have occurred by a shifting upward of the zooplankton population from the 100-to the 50-meter level, the 150-to the 100-meter level, etc. It would appear that the greater volumes of the night hauls at all levels above 300 meters may be explained by the migration of zooplankton from below this depth, by the plankton's escaping the net to a much greater extent during daylight hours, or by a combination of both factors. The possibility that this difference in catch rate is not the result of an elaborate diurnal migration[3] but rather of a simple dodging of the net during daylight hours, as suggested by Franz (1913), has been the subject of considerable speculation on the part of plankton biologists but has actually received little experimental effort.

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[2] Bigelow and Sears (1939) and also Clarke (1940) considered the crustaceans, chaetognaths, and molluscs as being of high nutritive value. It was our judgment, however, that the heteropod molluscs of the family Pterotracheidae, which are of common occurrence in the plankton of the tropics and subtropics of the Pacific, do not belong with this group because of their watery structure and should be classed with the nonnutritious forms.

On cruise 9 of the *John R. Manning* a sampling experiment was conducted to determine (1) the variation between a series of day hauls and night hauls at the same locality, and (2) variations between two localities not widely separated in distance and time. The results, graphically portrayed in figure 4, when examined by an analysis of variance, indicate no significant difference ($P > 0.05$) between stations no significant difference ($P > 0.05$) between times (day or night), but show a highly significant ($P < 0.01$) interaction (table 1). This latter feature results from the fact that the day-night variation was markedly different for the two localities: the night/day ratio was 1.04 for stations 1 and 2, and 1.50 for stations 3 and 4. We cannot account for this difference; weather and sea conditions varied very little during th $1\frac{1}{2}$-day period in which the hauls were made and without a detailed count of organisms in the samples, there were no apparent differences in composition. The close correspondence within each series of four hauls is further assurance, however, that the method of hauling is capable of producing repeatable results.

Another experiment conducted on cruise 9 of the *John R. Manning* was designed to measure differences among oblique hauls to three depths, 200, 300, and 500 meters, with samples taken at approximately hourly intervals over a 24-hour period. The hauls were made by running the vessel between drifting buoys which were lighted at night; therefore discounting wind, we were sampling the same surface water mass throughout the 24-hour period, although there was a westerly drift of about 30 miles during this time. The results shown in figure 5, when tested with an analysis of variance (table 2), yielded the following conclusions: (1) differences among times of hauling, with the 24-hour series divided into four 6-hour periods, were highly significant ($P < 0.01$); (2) differences among depths were also highly significant ($P < 0.01$); while the interaction or sampling error was non-significant ($P > 0.05$). The latte indicates that the variation with time followed the same pattern for all

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[3] The phenomenon of vertical migration has been comprehensively reviewed by Kikuchi (1930) and more recently by Cushing (1951).

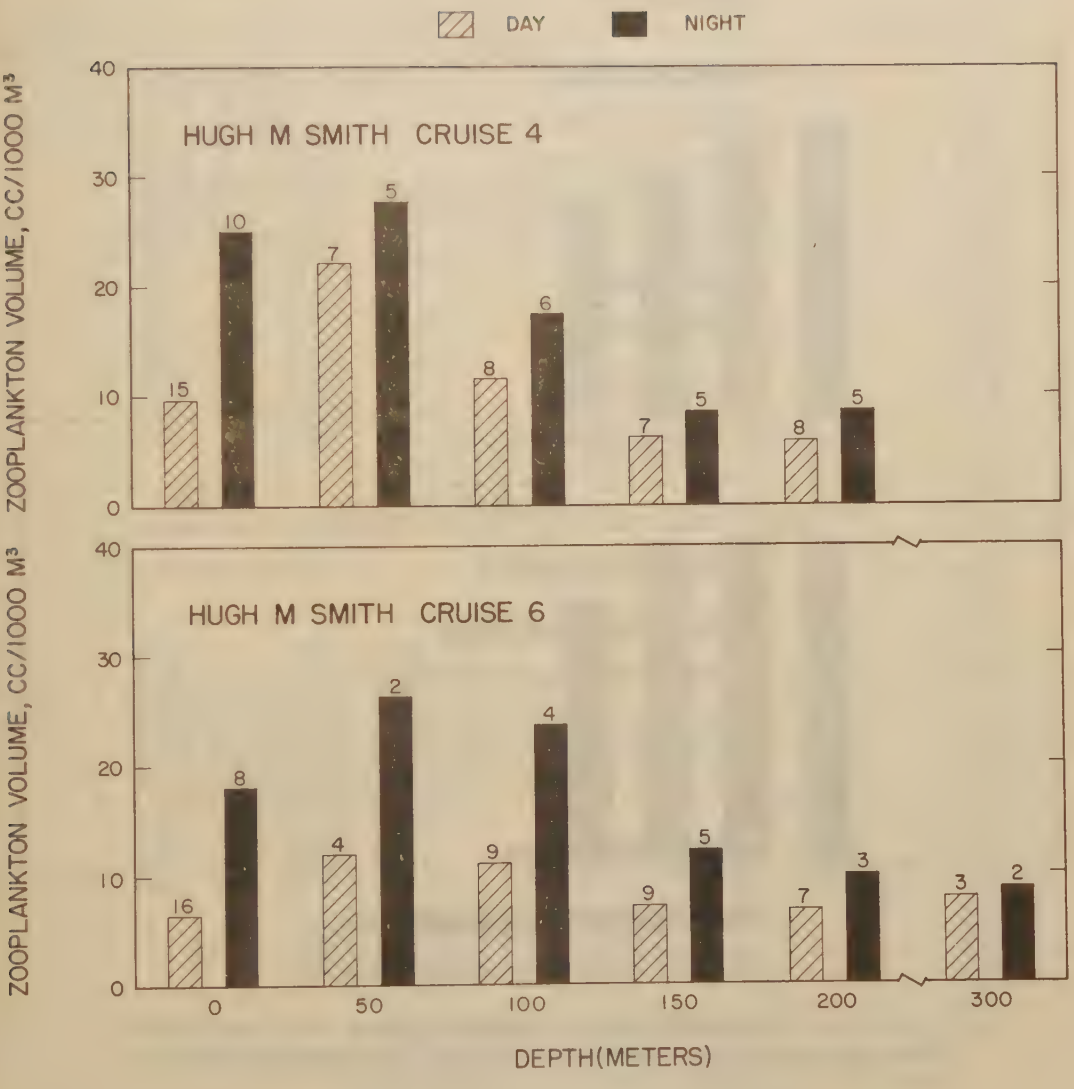


FIG. 3. COMPARISON OF AVERAGE ZOOPLANKTON VOLUMES RESULTING FROM DAY AND NIGHT HORIZONTAL HAULS AT DIFFERENT DEPTHS; CRUISES 4 AND 6, HUGH M. SMITH. (NUMBER OF SAMPLES IS INDICATED ABOVE EACH BLOCK).

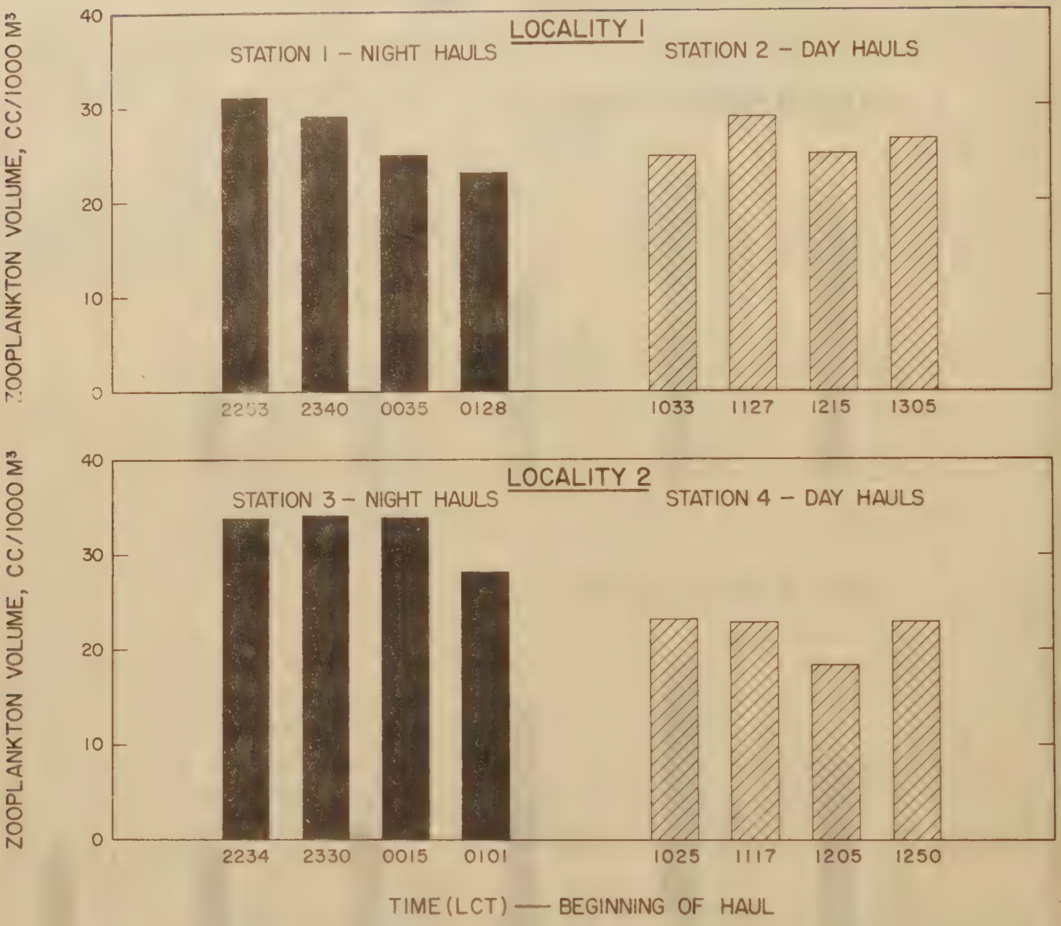


FIG. 4. ZOOPLANKTON VOLUMES COLLECTED AT FOUR STATIONS (TWO LOCALITIES) ON *JOHN R. MANNING* CRUISE 9 COMPARING LOCALITIES, STATIONS AND TIME OF SAMPLING.

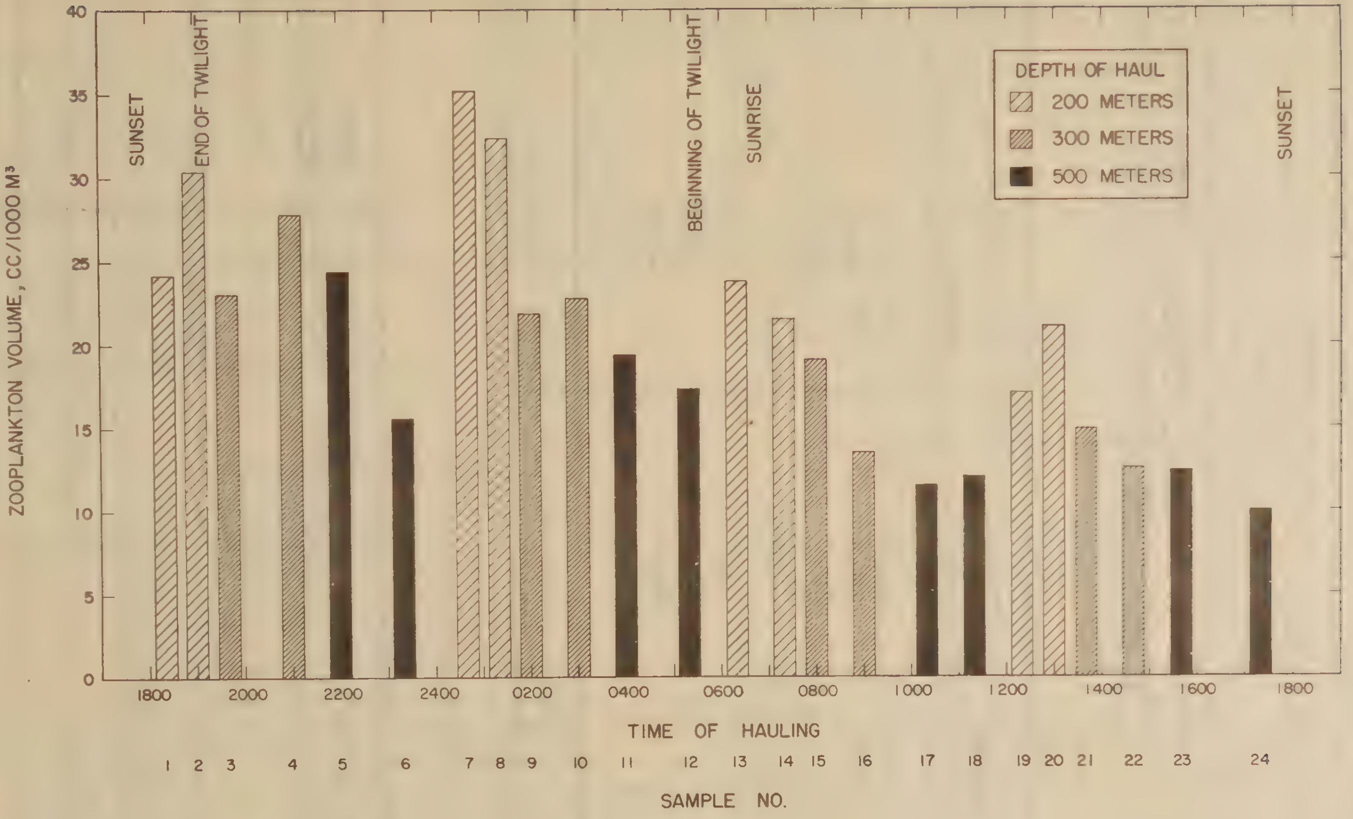


FIG. 5. ZOOPLANKTON VOLUMES FOR A 24-HOUR SERIES OF SUCCESSIVE OBLIQUE HAULS TO 200, 300, AND 500 METERS DEPTH, FROM JOHN R. MANNING CRUISE 9, STATION 5.

three depths. The correspondence within the paired hauls was satisfactory. Table 3 indicates that the coefficient of variation increased with depth -- signifying that, in relation to the means, the variation among samples increased with greater depth.

Table 1. Analysis of variance of zooplankton volumes collected on cruise 9, *John R. Manning*, showing differences between day and night samples at two localities northwest of Oahu.

Time	Sample	Locality		Mean
		A (Stations 1 and 2)	B (Stations 3 and 4)	
Night	1	31.2	33.7	
	2	29.3	34.2	29.9
	3	25.0	34.0	
	4	23.2	28.3	
Day	1	24.7	23.2	
	2	29.1	22.9	24.1
	3	24.9	18.4	
	4	26.6	22.9	
Mean		27.2	26.8	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Localities	1	0.81	0.81	0.01	> 0.05
Times	1	133.40	133.40	1.37	> 0.05
Locality x time interaction	1	97.02	97.02**	13.01	< 0.01
Within subclasses	12	93.84	7.82		
Total	15	325.07			

** Indicates a highly significant mean square value.

Table 2. Analysis of variance of zooplankton volumes collected on a 24-hour series of successive oblique hauls to 200, 300, and 500 meters, obtained on cruise 9, *John R. Manning*.

Haul depth	Time (6-hour periods)				Mean
	A	B	C	D	
	(1800 - 0000)	(0000 - 0600)	(0600 - 1200)	(1200 - 1800)	
200 m.	24.2	35.2	23.8	17.2	25.6
	30.4	32.4	21.6	20.1	
300 m.	23.1	21.9	19.2	14.9	19.5
	27.8	22.8	13.6	12.6	
500 m.	24.5	19.4	11.6	12.4	15.4
	15.7	17.4	12.1	10.0	
Mean	24.3	24.8	17.0	14.5	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Times	3	484.49	161.50**	15.08	< 0.01
Depths	2	423.67	211.84**	19.78	< 0.01
Time X depth interaction	6	64.25	10.71	1.24	> 0.05
Within subclasses	12	103.27	8.61		
Total	23	1075.68			

** Indicates a highly significant mean square value.

Table 3. Summary of certain statistics calculated for the 24-hour series of oblique hauls to three depths made on cruise 9, John R. Manning.

	Depth of haul (meters)		
	200	300	500
Number of samples	8	8	8
Mean sample volume (cc./1000 m.^{3})	25.6	19.5	15.4
Standard deviation (s) of mean volume	6.4	5.4	4.9
Coefficient of variation (C) of mean volume	24.8%	27.5%	31.7%
Night/day ratio	1.72	1.58	1.67
Coefficient of regression (b) of zooplankton volume on sine function	0.1379	0.1456	0.1300
"t" value for significance of the regression	8.673	4.853	2.902
P " " " " " "	< 0.001	< 0.01	> 0.05
Correlation coefficient (r), for zooplankton volumes and sine function	0.961	0.891	0.764
Coefficient of determination (r^2)	0.924	0.794	0.584

The experiment showed that the 200-meter oblique haul produced larger zooplankton volumes per unit of water strained than did the 300-meter or 500-meter hauls, thus indicating that within the range of depths sampled the largest amounts of zooplankton were found between 200 meters and the surface during both day and night periods. Judging from the night/day ratios (table 3), the volumes of the deeper hauls were as much affected by the diurnal variation as were the 200-meter hauls. In view of these circumstances, together with the saving in vessel time for the shallower hauls, we believe that of the three depths tested, the 200-meter oblique haul provides the most satisfactory method for estimating the abundance of zooplankton in the upper level of the ocean - the environment of the tunas.

An important source of variation in quantitative measurements of zooplankton abundance is related, therefore, to the time of day of hauling. In Hawaiian waters the volumes of night hauls, using a 200-meter oblique tow, have averaged about 1½ times the volumes of day hauls. This is sufficient variation to obscure the geographical and seasonal features of distribution which are of primary interest in this study. An adjustment to remove the effect of diurnal change in volume is the obvious solution to this difficulty. A suitable adjustment must not only take into account the contrast between full daylight and nighttime conditions but also the intermediate dawn and twilight effects on plankton volume.

Presumably the difference between day and night hauls is due either to an augmentation in the upper strata of water by upward migration of the plankton at night or to a reduction in catch in the daytime owing to greater ability of the plankton to dodge the net when there is light, or to a combination of these two. In any case, one would expect the amount caught to depend basically on the amount of plankton generally present at the time and place of hauling and the diurnal change to be a percentage of that amount. This being true, the plankton volumes should either be expressed as ratios to the basic population level or as logarithms. The logarithmic transformation is by far the most convenient and has the additional advantage of correcting for the natural skewness in the zooplankton volumes when arranged according to frequency of occurrence; after transformation the frequency distribution more closely approximates a normal distribution.

The authors are indebted to O. E. Sette for suggesting the method, which we present here, for adjusting the zooplankton data for this diurnal variation. As we are not aware of any previous references to this method in plankton literature, we will describe it in some detail.

Method of Adjusting for Diurnal Variation

To study the nature of the diurnal cycle it would be desirable to have zooplankton hauls made throughout the day and night in the same place or in the same water mass, so that geographical, ecological, or faunal differences would not obscure the diurnal cycle. Among the hauls available to us the group resulting from Manning cruise 8 most nearly approaches this condition. On this cruise a set of 9 stations on a 160-mile section on 158° 25' W. longitude, lying just west of the island of Oahu, was visited weekly for 4 weeks, with hauls made around the clock as the stations were reached in consecutive order.

If the logarithms of the plankton volumes are plotted as ordinates against time of day as the abscissa, without regard to date or locality and with midnight at the center of the abscissa, as in figure 6, it is seen that there is a period from about 1900 to 0600 hours when catches are high and a period from about 0800 to 1800 hours when they are low. The hours from 0400 to 0800 and from 1600 to 2000 appear to include the periods of maximum change. A mathematical curve approximately describing this type of change is the sine function, when midnight is equated to the angle whose sine is $+1.0$ (fig. 7). To fit this curve to

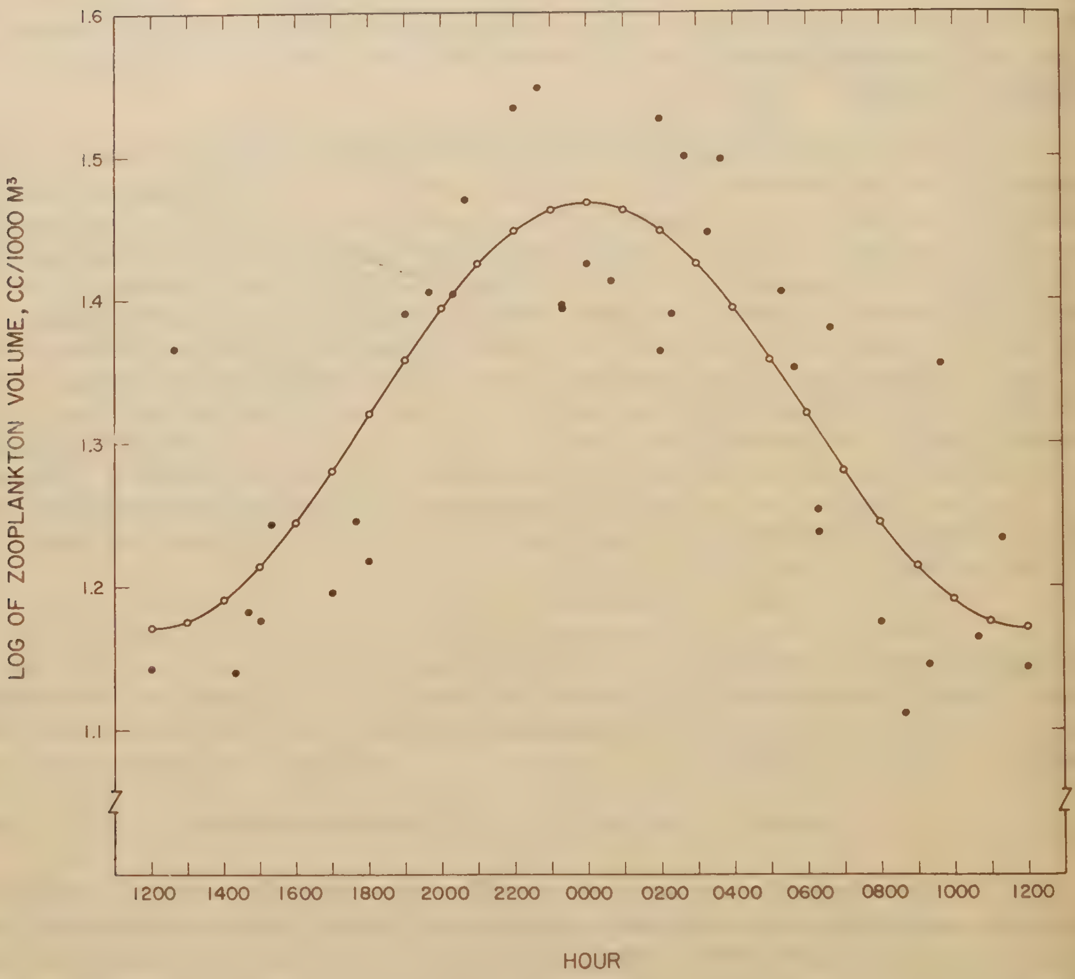


FIG. 6. LOGARITHMS OF ZOOPLANKTON VOLUMES COLLECTED ON JOHN R. MANNING CRUISE 8, PLOTTED AGAINST HOUR OF HAULING TO DEMONSTRATE THE RESEMBLANCE BETWEEN VARIATION WITH TIME OF HAULING AND THE SINE CURVE (FIG. 7).

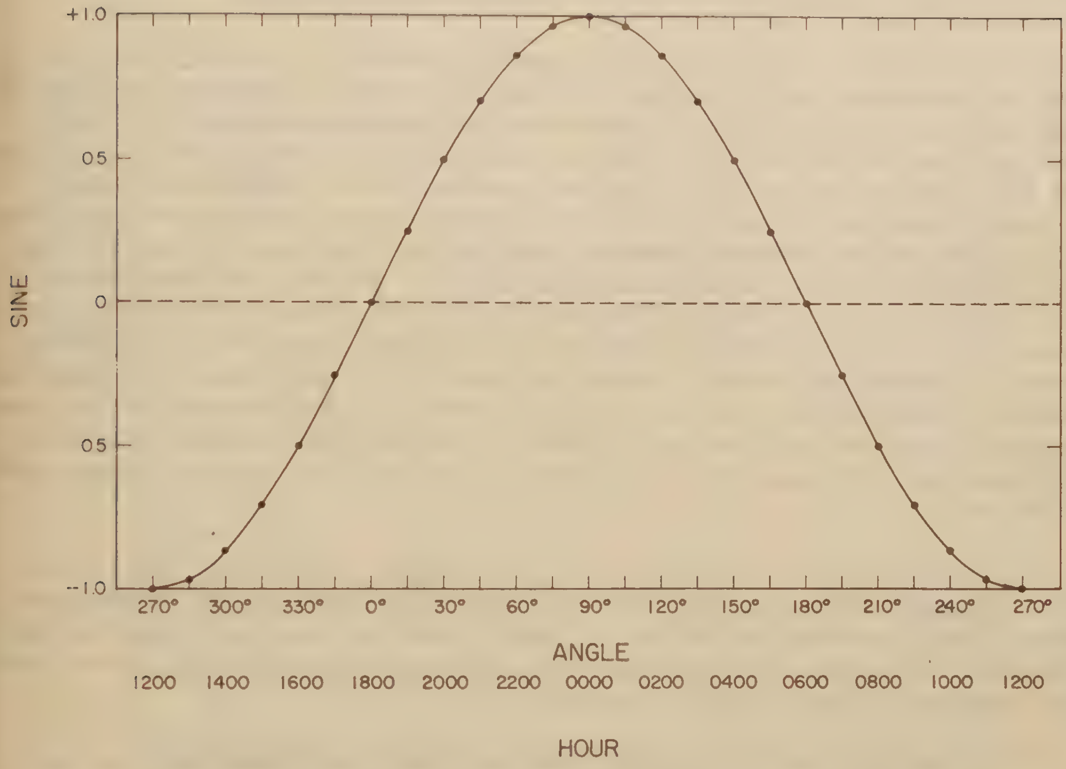


FIG. 7. GRAPH OF THE SINE CURVE SHOWING RELATIONSHIP BETWEEN THE SINE FUNCTION AND CORRESPONDING HOUR OF THE DAY WHEN THE 1800 HOUR IS EQUATED TO ANGLE WHOSE SINE IS ZERO.

the data of figure 6 it is only necessary to transform the abscissa to the sine of the angle, replot as in figure 8, and fit a straight line to the new nearly rectilinear distribution of values. Transferring the straight line to the coordinates of figure 6 produces the curve drawn there, which is seen to describe fairly well the general course of chang in logarithmic plankton volume with time of day. The scatter to both sides of the curve is considerable and presumably reflects chance variations, locality differences, and the discrepancies between the arbitrary sine function and the true nature of the diurnal change.

That for this particular cruise there is a discrepancy between the mathematical function and the empirical situation is suggested by the excess of points above the curve in the neighborhood of 0400 hours and the deficiencies in the neighborhood of 1600 hours. It appears that the rise in the catches begins somewhat later in the afternoon and then rises more steeply than the corresponding sine curve, and that the decline in the morning departs similarly. We have not tested the significance of these departures, but similar graphs for the data of other cruises do not show any consistency in the time or direction of discrepancies. It is probable that the sine curve describes the general diurnal fluctuation as well as may be expected of any simple mathematical function. It accounts for an important part of the variability in the plankton hauls, as may be seen from the coefficient of determination (r^2) (Ezekiel 1950, p. 139), as given in table 7 for each of the several cruises.

Accepting, then, the sine function as describing the locus of the diurnal cycle and the fitted regression line in the transformed data as the quantitative effect of this cycle on the particular group of hauls for cruise 8, the adjustment to remove the diurnal effect has been computed as set forth in table 4.

Cruise 8 of the *Manning* was not designed, however, to investigate the diurnal cycle, but was intended to determine whether or not there was any indication of a definite decline or increase in the plankton during the late summer season. A series of stations, rather than a single one, was selected to give a more general sampling of the plankton population and therefore general significance to any change which might be observed. An analysis of variance of the unadjusted data (table 5), with two-way classification (following Snedecor 1946), indicates no significant differences among stations nor among weeks. The mean square for discrepance is large, however, and tends to render less sensitive the test of significance for the other mean square values. Analysis of the adjusted data (table 5) shows a greatly reduced total variance from that of the unadjusted data, indicating that the chief source of variation was the time of hauling. The mean square for weeks now emerges as larger than that of the discrepance and just under the 0.05 level of significance. Although we still conclude that there were not significant differences among stations or among weeks during the period of sampling, we now gain the idea that the weekly difference is much more important than the locality differences. Variation in zooplankton volume with sampling time and the smoothing effect of the sine adjustment on the data are illustrated in figure 9.

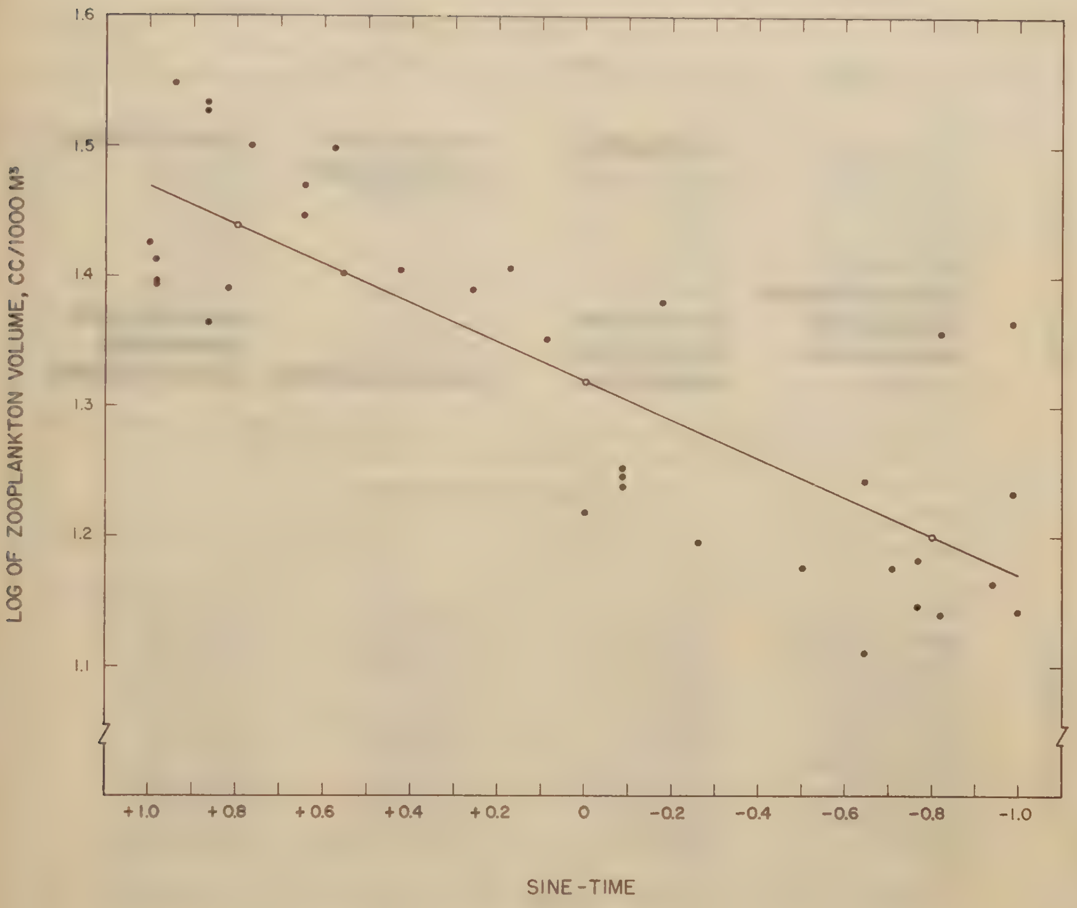


FIG. 8. LOGARITHMS OF ZOOPLANKTON VOLUMES OF JOHN R. MANNING CRUISE 8, PLOTTED AGAINST THE SINE VALUE CORRESPONDING TO THE HOUR OF HAULING, AND SHOWING THE REGRESSION LINE CALCULATED FOR THE RELATIONSHIP.

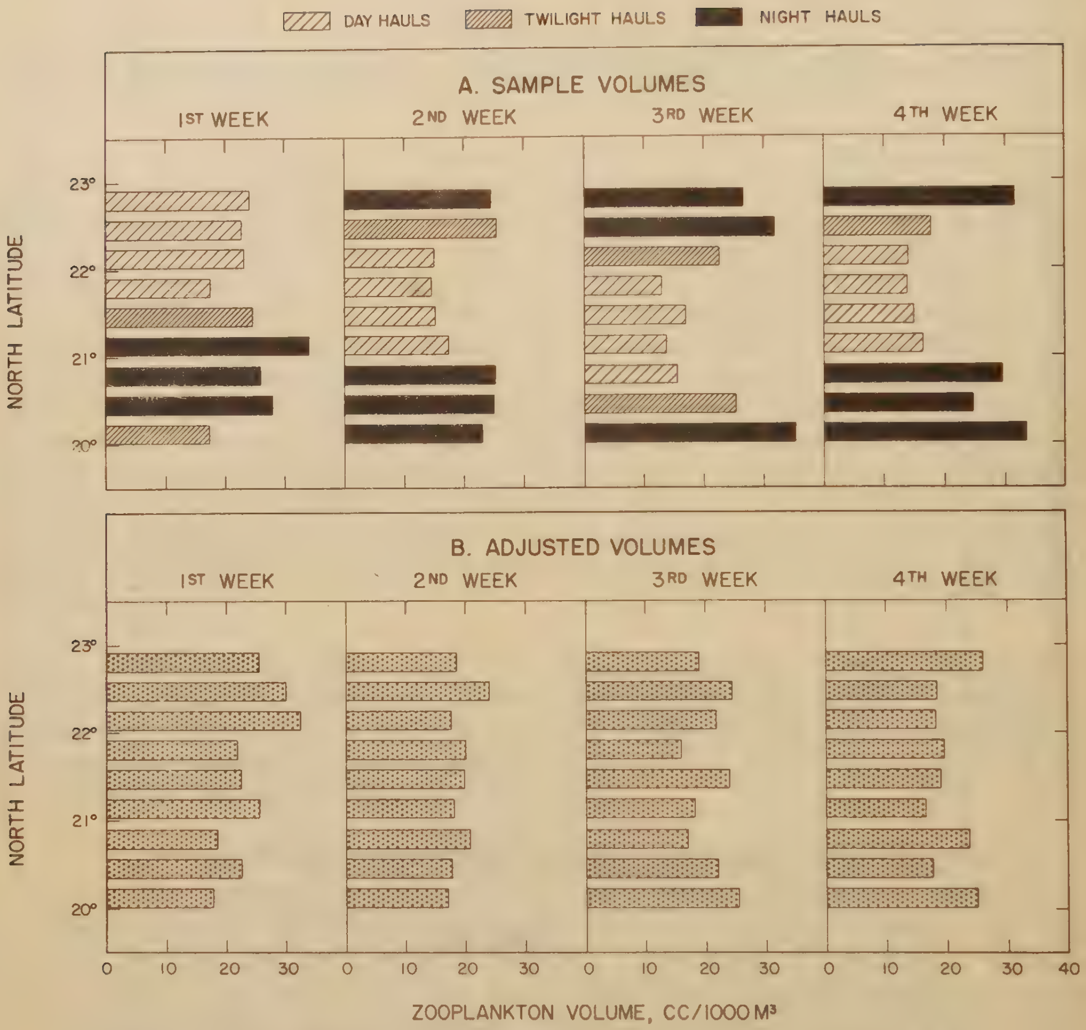


FIG. 9. ZOOPLANKTON VOLUMES, COLLECTED ON THE NORTH-SOUTH SECTION ALONG 158° 25' W. LONGITUDE ON JOHN R MANNING CRUISE 8, BEFORE (A) AND AFTER (B) ADJUSTMENT BY THE SINE METHOD TO EQUILIBRATE FOR THE DIURNAL VARIATION.

Table 4. Calculations for the sine method of adjusting zooplankton sample volumes for differences related to time of day of hauling, using as an example volumes from cruise 8, *John R. Manning*.

ta-ion	Time (LCT)	Mid-time	Sample volume, cc./1000m.^{3}	Y Log of volume	X Sine-time	bX	Y-bX	Adjusted volume, cc./1000m.^{3}
1	0640 - 0654	0640	24.0	1.380	-.174	-.026	1.406	25.5
2	0930 - 1005	0940	22.7	1.356	-.819	-.122	1.478	30.1
3	1217 - 1253	1240	23.1	1.364	-.985	-.147	1.511	32.4
4	1506 - 1545	1520	17.5	1.243	-.643	-.096	1.339	21.8
5	1837 - 1918	1900	24.6	1.391	.259	.039	1.352	22.5
6	2132 - 2210	2200	34.1	1.533	.866	.129	1.404	25.4
7	0021 - 0100	0040	25.9	1.413	.985	.147	1.266	18.5
8	0305 - 0343	0320	28.0	1.447	.643	.096	1.351	22.4
9	0606 - 0642	0620	17.3	1.238	-.087	-.013	1.251	17.8
15	0204 - 0240	0220	24.6	1.391	.819	.122	1.269	18.6
16	0455 - 0537	0520	25.5	1.406	.174	.026	1.380	24.0
17	0741 - 0816	0800	15.0	1.176	-.500	-.074	1.250	17.8
18	1026 - 1054	1040	14.6	1.164	-.940	-.140	1.304	20.1
19	1430 - 1508	1440	15.2	1.182	-.766	-.114	1.296	19.8
20	1714 - 1748	1740	17.6	1.246	-.087	-.013	1.259	18.2
21	2007 - 2040	2020	25.3	1.403	.574	.085	1.318	20.8
22	2253 - 2329	2320	24.9	1.396	.985	.147	1.249	17.7
23	0149 - 0222	0200	23.1	1.364	.866	.129	1.235	17.2
27	2343 - 0012	0000	26.7	1.426	1.000	.149	1.277	18.9
28	0230 - 0306	0240	31.6	1.500	.766	.114	1.386	24.3
29	0525 - 0600	0540	22.5	1.352	.087	.013	1.339	21.8
30	0817 - 0850	0840	12.9	1.111	-.643	-.096	1.207	16.1
31	1107 - 1140	1120	17.1	1.233	-.985	-.147	1.380	24.0
32	1355 - 1427	1420	13.8	1.140	-.819	-.122	1.262	18.3
33	1640 - 1710	1700	15.7	1.196	-.259	-.039	1.235	17.2
34	1921 - 1954	1940	25.4	1.405	.423	.063	1.342	22.0
35	2225 - 2259	2240	35.3	1.548	.940	.140	1.408	25.6
38	0330 - 0402	0340	31.5	1.498	.574	.085	1.413	25.9
39	0612 - 0645	0620	17.9	1.253	-.087	-.013	1.266	18.4
40	0859 - 0931	0920	14.0	1.146	-.766	-.114	1.260	18.2
41	1144 - 1214	1200	13.9	1.143	-1.000	-.149	1.292	19.6
42	1450 - 1522	1500	15.0	1.176	-.707	-.105	1.281	19.1
43	1737 - 1808	1800	16.5	1.218	.000	.000	1.218	16.5
44	2021 - 2049	2040	29.5	1.470	.643	.096	1.374	23.7
45	2308 - 2341	2320	24.8	1.394	.985	.147	1.247	17.7
46	0150 - 0222	0200	33.6	1.526	.866	.129	1.397	24.9

S	800.7	2.188	762.8
n	36	36	36
Mean	22.24	0.061	21.19

Table 4. Calculations for the sine method of adjusting zooplankton sample volumes for differences related to time of day of hauling, using as an example volumes from cruise 8, John R. Manning. (Cont'd.)

$n = 36$
$SX = 2.188$
$\bar{x} = 0.061$
$SX^2 = 18.107260$
$(SX)^2/n = \underline{0.132982}$
$Sx^2 \quad 17.874278$

$SY = 47.828$
$\bar{y} = 1.3286$
$SY^2 = 64.133048$
$(SY)^2/n = \underline{63.542155}$
$Sy^2 \quad 0.590893$

$SXY = 5.566545$
$(SX)(SY)/n = 2.906880$
$Sxy = 2.659665$

$$b = Sxy/Sx^2$$
$$= 2.659665/17.874278 = \underline{0.1488}$$

$$\hat{Y} = \bar{y} + b\,(X - \bar{x})$$
$$= 1.3195 + 0.1488\ X$$

Test of significance of the regression:

$$Sd_{y.x}^2 = Sy^2 - (Sxy)^2/Sx^2 = \underline{0.195139}$$

$$s_{y.x}^2 = Sd_{y.x}^2/n-2 = \underline{0.005739}$$

$$s_b^2 = s_{y.x}^2/Sx^2 = \underline{0.00032110}$$

$$s_b = \underline{0.0179}$$

$$t = b/s_b = \underline{8.313},\ P < 0.001$$

With 34 degrees of freedom, $t_{.001} = 3.608$; thus there is evidenced a highly significant regression of Y on X.

Table 5. Demonstration of differences between adjusted and unadjusted zooplankton volumes (cc./1000 m.^{3}), using samples from cruise 8, John R. Manning.

A. Analysis of variance of the unadjusted data, showing largest mean square values associated with stations and with discrepance, as a result of the large day-night difference among samples.

Station	Week				Mean
	1	2	3	4	
1, 15, 27, 38	24.0	24.6	26.7	31.5	26.7
2, 16, 28, 39	22.7	25.5	31.6	17.9	24.4
3, 17, 29, 40	23.1	15.0	22.5	14.0	18.6
4, 18, 30, 41	17.5	14.6	12.9	13.9	14.7
5, 19, 31, 42	24.6	15.2	17.1	15.0	18.0
6, 20, 32, 43	34.1	17.6	13.8	16.5	20.5
7, 21, 33, 44	25.9	25.3	15.7	29.5	24.1
8, 22, 34, 45	28.0	24.9	25.4	24.8	25.8
9, 23, 35, 46	17.3	23.1	35.3	33.6	27.3
Mean	24.1	20.6	22.3	21.9	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	8	628.24	78.53	2.34	> 0.05
Weeks	3	56.58	18.86	0.56	> 0.05
Discrepance	24	805.65	33.57		
Total	35	1490.47			

Table 5 (Cont'd.)

B. Analysis of variance of the adjusted data, showing the largest mean square value now related to weeks.

Station	Week				Mean
	1	2	3	4	
1, 15, 27, 38	25.5	18.6	18.9	25.9	22.2
2, 16, 28, 39	30.1	24.0	24.3	18.4	24.2
3, 17, 29, 40	32.4	17.8	21.8	18.2	22.6
4, 18, 30, 41	21.8	20.1	16.1	19.6	19.4
5, 19, 31, 42	22.5	19.8	24.0	19.1	21.4
6, 20, 32, 43	25.4	18.2	18.3	16.5	19.6
7, 21, 33, 44	18.5	20.8	17.2	23.7	20.0
8, 22, 34, 45	22.4	17.8	22.0	17.7	20.0
9, 23, 35, 46	17.8	17.2	25.6	24.9	21.4
Mean	24.0	19.4	20.9	20.4	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	8	82.20	10.28	0.74	> 0.05
Weeks	3	108.96	36.32	2.63	> 0.05
Discrepance	24	331.71	13.82		
Total	35	522.87			

The 24-hour series of oblique hauls made on Manning cruise 9 affords a further test of the sine method of adjustment. As previously stated, the series consisted of paired oblique hauls to three depths --200, 300, and 500 meters--all taken within a relatively small area. The results of the adjustment for the three depths are shown in table 10. As evidenced by the coefficient of determination (r^2), for the 200-meter hauls 92 percent of the variation in the zooplankton volumes is associated with correlated changes in the sine function. The degree of correlation is less, however, for the 300-meter hauls and still less for the 500-meter hauls. This is accompanied by a parallel decrease in the significance of the regression of Y (zooplankton volumes) on X (sine function).

Data from all seven cruises in local waters were adjusted by the sine method. The adjusted values for cruises employing 200-meter oblique hauls are given in tables 18, 19, 20, 21, and 22; adjusted values for cruises employing horizontal hauls are given in table 6. Table 7 provides a comparison of the results of the adjustment for the various cruises. Among the 200-meter oblique hauls the night/day ratio for unadjusted volumes ranged from 1.30 to 1.70, while for the adjusted volumes the ratio varied from 0.97 to 1.05. For the horizontal hauls, after adjustment, the ratio ranged from 0.69 to 1.13, indicating the presence of considerable variation in the horizontal hauls which is possibly not associated with the day-night differences.

The high significance shown by the "t" tests for the regression of zooplankton volumes on the sine curve and the relatively high value of r^2 (table 7) are general evidence in favor of the method. It is conceivable, however, that both "t" and "r^2" might vary inversely with the amount of variation--other than diurnal--present in the data, even though the diurnal effect were constant. Therefore these two statistics possibly do not provide a crucial test of the adjustment method. Since this transformation appeared to correct--to a large extent at least--for the day-night differences among the 200-meter oblique hauls, the adjusted volumes were used for examining geographical and short-term variations and for correlations with environmental factors.

GEOGRAPHICAL AND TEMPORAL VARIATIONS

In figure 10 we have attempted to show lines of equal zooplankton concentration or "isoplankts" for the three cruises of the Hugh M. Smith which were based on 200-meter oblique hauls and provided general coverage of the area. From an examination of these charts we conclude that although the abundance of zooplankton was remarkably uniform throughout the Island waters, there were certain areas which were consistently richer or poorer than other areas. For example, stations southwest of Oahu, in all three cruises, produced volumes somewhat higher than average. Also, an area north of Kauai showed an unusually high concentration on two cruises. The southeast corner of the survey area produced consistently low catches.

Table 6. Adjusted zooplankton volumes, cc/1000 m.^{3}, for the surface hauls and for the mean of three horizontal hauls at each station of cruises 4 and 6 of the *Hugh M. Smith*.

A. Cruise 4, May 1950.

Station	Haul depths, meters	Surface sample volume	Surface adjusted volume	Mean volume for 3 depths	Adjusted mean volume
1	0, 50, 150	10.7	23.6	13.8	20.3
1A	0, 50, 150	25.7	25.7	19.6	19.6
2	0, 100, 200	9.4	4.1	15.9	10.6
3	0, 50, 150	2.3	5.1	9.7	14.3
4	0, 100, 200	9.4	11.0	8.5	9.2
5	0, 50, 150	21.5	8.9	19.1	12.4
6	0, 100, 200	1.2	3.0	3.8	5.9
7	0, 50, 150	142.3	112.2	53.2	47.3
8	0, 100, 200	20.6	11.5	15.2	11.4
9	0, 50, 150	4.9	11.6	8.9	13.5
10	0, 100, 200	5.1	8.6	12.4	16.0
11	0, 50, 150	44.6	17.9	25.5	16.3
12	0, 100, 200	35.3	32.6	19.4	18.7
13	0, 50, 150	29.3	13.9	22.6	15.7
14	0, 100, 200	9.6	22.6	8.6	13.1
15	0, 50, 150	10.0	13.7	10.7	12.4
16	0, 100, 200	14.8	6.0	12.2	7.8
17	0, 50, 150	22.2	24.0	15.5	16.1
18	0, 100, 200	2.2	3.5	6.3	7.9
19	0, 50, 150	19.5	7.9	21.1	13.6
20	0, 100, 200	4.0	8.5	7.2	10.4
21	0, 50, 150	9.6	11.3	16.0	17.3
22	0, 100, 200	30.0	13.6	19.2	13.0
23	0, 50, 150	43.9	32.1	26.7	22.9
24	0, 100, 200	29.5	56.4	16.0	21.9
25	0, 50, 150	5.3	11.7	10.7	15.7
26	0, 100, 200	22.1	10.4	15.6	10.8
27	0, 50, 150	23.8	11.8	18.3	13.0
28	0, 100, 200	16.4	15.1	9.8	9.4
Mean		21.6	18.6	15.9	15.1

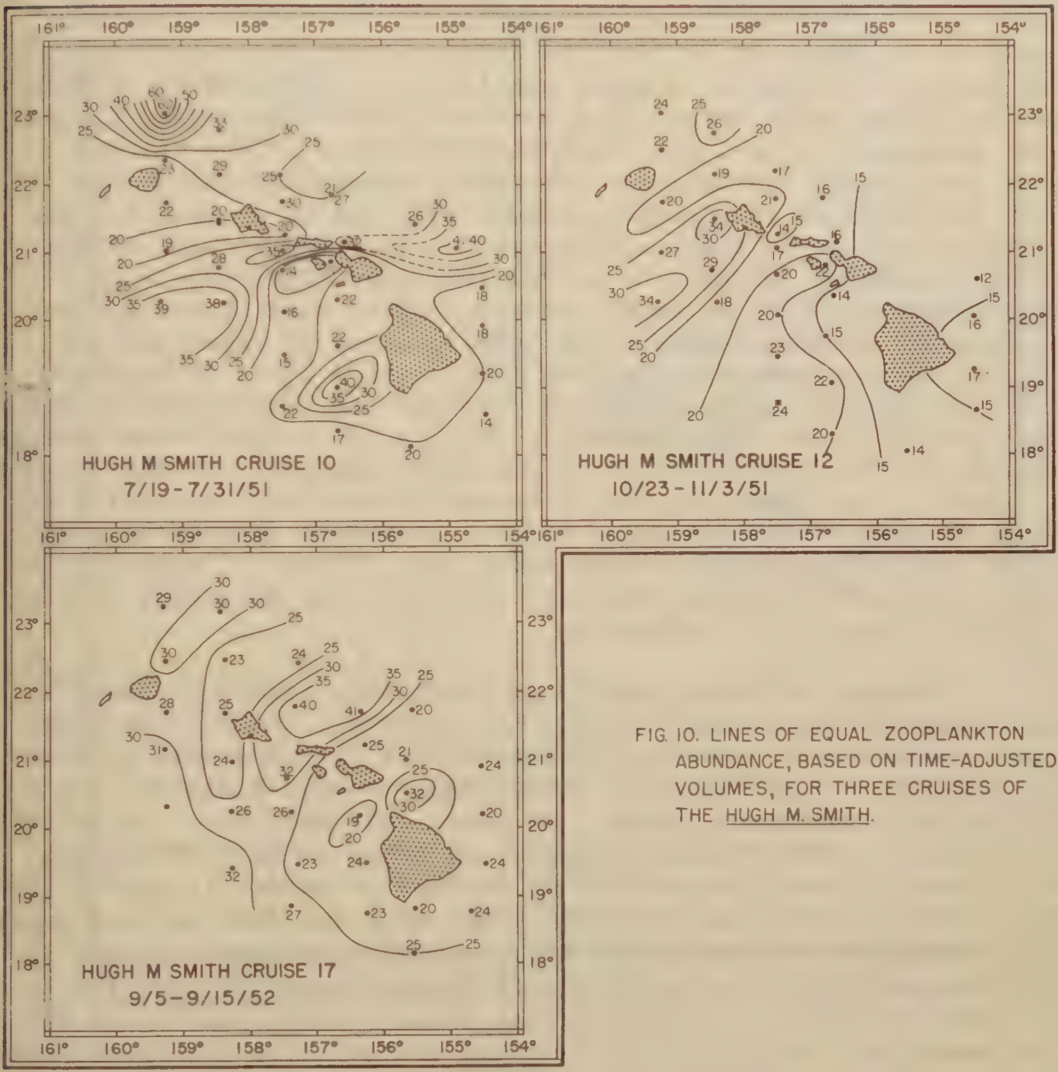
Table 6. (Cont'd)

B. Cruise 6, August 1950

Station	Haul depths, meters	Surface sample volume	Surface adjusted volume	Mean volume for 3 depths	Adjusted mean volume
1	0, 50, 150	5.2	9.9	8.2	11.6
1A	0, 50, 150	8.1	5.0	14.1	10.9
2	0, 100, 200	7.4	4.5	11.1	8.9
3	0, 50, 150	2.4	5.5	5.7	8.9
4	0, 100, 200	8.8	7.6	7.8	7.2
5	0, 150, 300	7.4	3.4	8.7	5.8
6	0, 100, 200	4.8	10.6	7.3	11.1
7	0, 50, 150	16.5	11.6	13.2	10.9
8	0, 100, 200	14.8	14.8	12.6	12.6
9	0, 50, 150	4.3	8.2	6.7	9.4
10	0, 150, 300	11.4	4.9	11.3	7.2
11	0, 50, 150	17.9	16.6	13.6	13.1
12	0, 100, 200	3.7	8.0	6.9	10.4
13	0, 50, 150	42.6	45.8	26.9	28.0
14	0, 100, 200	11.2	11.2	9.4	9.4
15	0, 150, 300	19.6	8.5	17.3	11.1
16	0, 100, 200	7.4	12.7	7.8	10.4
17	0, 150, 200	2.0	3.1	7.3	9.1
18	0, 100, 200	36.8	20.2	24.2	17.7
19	0, 150, 200	23.6	10.1	19.2	12.3
20	0, 150, 300	3.5	6.7	7.2	10.1
21	0, 150, 200	14.1	25.6	9.4	12.9
22	0, 100, 200	88.3	76.2	36.6	33.9
23	0, 50, 150	1.9	4.3	6.4	9.9
24	0, 100, 200	17.1	7.7	19.9	13.1
25	0, 150, 300	4.8	7.3	7.4	9.2
26	0, 100, 200	14.0	21.4	9.3	11.6
27	0, 50, 150	25.7	12.9	19.5	13.5
28	0, 100, 200	3.2	7.4	10.7	16.7
Mean		14.8	13.5	12.6	12.3

Table 7. Summary of results of adjustment by the sine method for data from 7 cruises in Hawaiian waters. The coefficient of determination, r^2, represents the fraction of the variation in the plankton volumes associated with the correlated changes in plankton volume and the sine function.

Cruise	Period	Type of haul	Mean volume, cc./1000 m.^{3}		Night/day ratio		b	t	df	P	r^2
			Un-adjusted	Adjusted	Un-adjusted volumes	Adjusted volume					
HMS-4	May 1950	horizontal (surface)	21.6	18.6	2.42	0.69	0.3972	4.355	27	<0.001	0.41
"	"	horizontal (mean of 3 levels)	15.9	15.1	1.71	0.90	0.1942	4.240	27	<0.001	0.40
HMS-6	Aug. 1950	horizontal (surface)	14.8	13.5	2.84	0.94	0.3672	4.377	27	<0.001	0.42
"	"	horizontal (mean of 3 levels)	12.6	12.3	2.10	1.13	0.1941	4.644	27	<0.001	0.44
HMS-10	July 1951	200m. oblique	26.0	25.6	1.39	0.97	0.1128	2.945	32	<0.01	0.21
JRM-8	Sept.-Oct. 1951	200m. oblique	22.2	21.2	1.70	1.03	0.1488	8.313	34	<0.001	0.67
HMS-12	Oct.-Nov. 1951	200m. oblique	20.2	20.3	1.57	1.04	0.1231	4.076	28	<0.001	0.37
JRM-9	Nov. 1951	200m. oblique	27.0	26.5	1.30	1.00	0.0688	5.375	30	<0.001	0.45
HMS-17	Sept. 1952	200m. oblique	26.5	26.4	1.47	1.05	0.1033	4.943	28	<0.001	0.47


HUGH M SMITH CRUISE 10
7/19-7/31/51

HUGH M SMITH CRUISE 12
10/23-11/3/51

HUGH M SMITH CRUISE 17
9/5-9/15/52

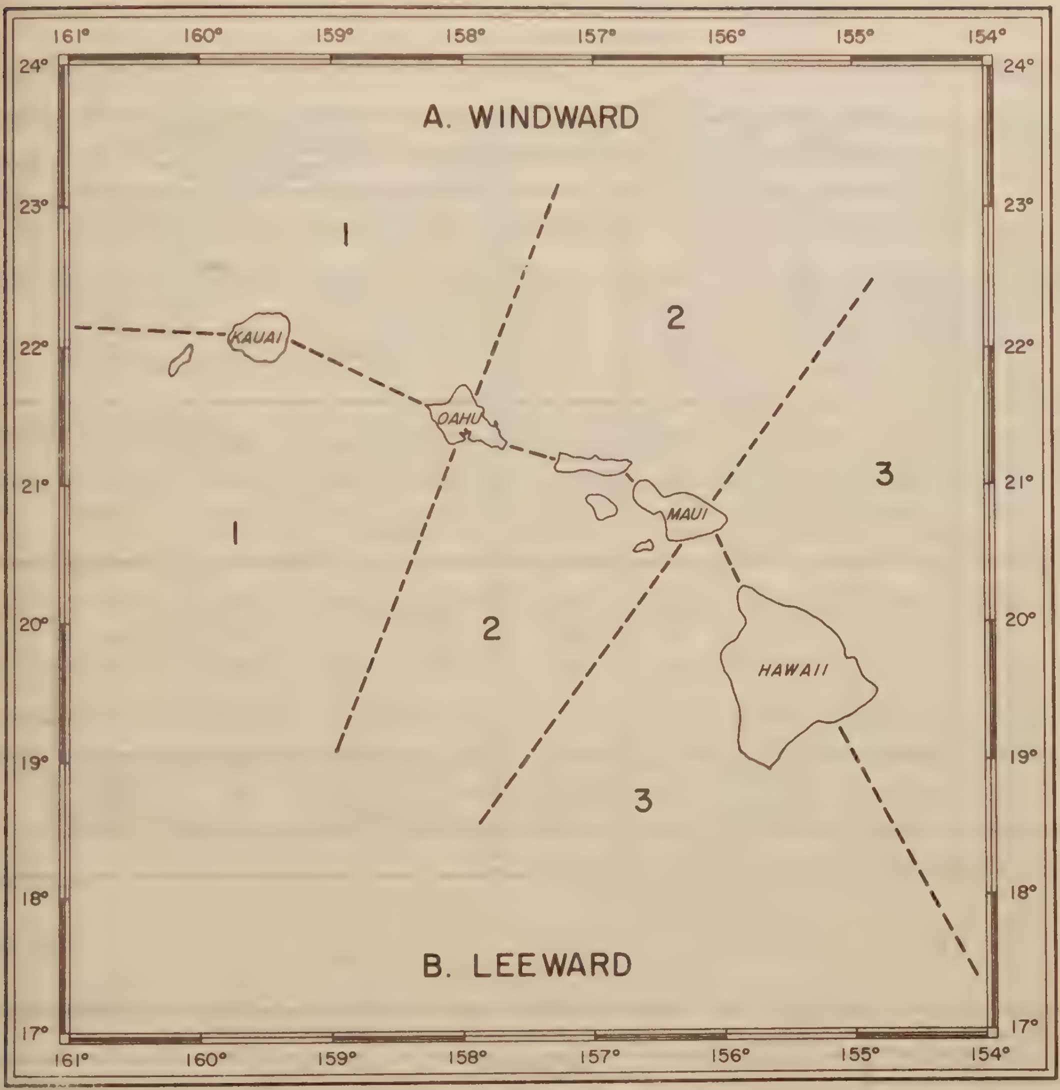
161°
160°
159°
158°
157°
156°
155°
154°
23°
22°
21°
20°
19°
18°

FIG. 10. LINES OF EQUAL ZOOPLANKTON ABUNDANCE, BASED ON TIME-ADJUSTED VOLUMES, FOR THREE CRUISES OF THE HUGH M. SMITH.

One hypothesis seeming worthy of testing was that areas to the lee of the island chain might be higher in zooplankton abundance than areas to windward because of the possible enrichment from the littoral waters of the islands and from the upwelling which may theoretically occur in the lee of oceanic islands. As the Hawaiian archipelago extends generally in a southeast-northwest direction, and since the prevailing tradewinds are from the northeast and the major ocean currents from the east and northeast, a line connecting the various islands of the group as in figure 11 divides the island waters into windward and leeward areas. In order to examine statistically differences between, and within, these major areas, they were each subdivided (fig. 11) into six subareas, three leeward and three windward of the islands. Using an analysis of variance, of completely randomized design, we compared the adjusted zooplankton volumes obtained on cruises 10, 12, and 17 of the Smith for these six subareas. From the results of the analysis, summarized in table 8, we conclude that there were significant differences ($P < 0.05$) among cruises, but no significant differences ($P > 0.05$) between windward and leeward areas or among the six subareas. From an examination of the means (table 8) it is apparent that, on the windward side, subarea 3 produced the lowest mean on all 3 cruises; subarea 2 was intermediate in rank in two of the three cruises, and subarea 1 ranked first in two of the three cruises. On the leeward side, subarea 3 was lowest in two of three cruises, but subareas 1 and 2 fail to follow in any particular order. Therefore, while the summary means for both windward and leeward areas show a trend of slightly increasing zooplankton volumes from east to west, the individual cruises do not follow this in all instances.

Although the seven cruises on which this report is based were not properly distributed in time to adequately describe seasonal or annual variations in plankton abundance, they provide some information of interest on differences in zooplankton abundance between the summer and fall seasons and between the years 1951 and 1952. It is evident from table 6 that the mean volumes collected in May 1950 (Smith cruise 4) were somewhat larger than the volumes collected in August 1950 (Smith cruise 6). The time-adjusted means, 15.1 cc./1000 m.^{3} for cruise 4 and 12.3 cc./1000 m.^{3} for cruise 6 are roughly indicative of the degree of change. Smith cruise 10 in July 1951 produced an adjusted mean of 25.6 cc./1000 m.^{3}, which is significantly different ($P < 0.05$) from the mean, 20.3 cc./1000 m.^{3}, of Smith cruise 12 in October-November 1951. Manning cruise 8, September-October 1951, which sampled along just one north-south section west of Oahu (fig. 2), was intermediate in time and also in zooplankton volume with a mean of 21.2 cc./1000 m.^{3}.

In table 9 we have assembled all data obtained during summer and fall of 1951 for the one section, stations 6 to 10 (as numbered on Smith cruise 10), and through an analysis of variance have examined the data for spatial and short-term variations. While the tests of significance indicate that there were no significant differences among stations ($P > 0.05$) or among visits ($P > 0.05$), the mean square value for visits is quite near the 0.05 level of probability.[4]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A. WINDWARD
1
2
3
KAUAI
OAHU
MAUI
HAWAII
1
2
3
B. LEEWARD

FIG. 11. CHART OF THE MAJOR HAWAIIAN ISLANDS SHOWING THE BOUNDARIES OF THE SIX GEOGRAPHICAL SUBDIVISIONS USED IN COMPARING AREAL DIFFERENCES IN ZOOPLANKTON ABUNDANCE.

Table 8. Analysis of variance of adjusted zooplankton volumes, cc./1000 m.^{3}, for different areas (shown in fig. 11) of the Hawaiian region, as obtained on three cruises of the *Hugh M. Smith* employing 200-meter oblique hauls.

Summary Table

Cruise		A. Windward area				B. Leeward area				Cruise total
		Sub-area				Sub-area				
		1	2	3	Total	1	2	3	Total	
HMS-10	S n $\bar{x}$	146.0 4 36.5	156.1 6 26.0	137.0 6 22.8	439.1 16 27.4	160.8 6 26.8	149.9 7 21.4	120.9 5 24.2	431.6 18 24.0	870.7 34 25.6
HMS-12	S n $\bar{x}$	90.4 4 22.6	84.5 5 16.9	60.3 4 15.1	235.2 13 18.1	142.8 5 28.6	134.8 7 19.3	95.4 5 19.1	373.0 17 21.9	608.2 30 20.3
HMS-17	S n $\bar{x}$	136.8 5 27.4	149.4 5 29.9	144.5 6 24.1	430.7 16 26.9	82.8 3 27.6	139.1 5 27.8	138.9 6 23.2	360.8 14 25.8	791.5 30 26.4
Area total	S n $\bar{x}$	373.2 13 28.7	390.0 16 24.4	341.8 16 21.4	1105.0 45 24.6	386.4 14 27.6	423.8 19 22.3	355.2 16 22.2	1165.4 49 23.8	2270.4 94 24.2

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Areas	1	13.97	13.97	0.08	> 0.05
Sub-areas	4	673.33	168.33	1.48	> 0.05
Cruises	12	1,368.57	114.05*	2.31	< 0.05
Stations	76	3,747.68	49.31		
Total	93	5,803.55			

* Indicates a significant mean square value.

Table 9. Analysis of variance of adjusted zooplankton volumes (cc./1000 m.^{3} for a series of 5 stations (numbered 6 to 10 on *Smith* cruise 10) just west of Oahu. The data were obtained on 6 traverses of the section during the period 7/22 to 10/26/51.

Visit	Date	Station					Mean
		6	7	8	9	10	
HMS-10	7/22-24	32.6	28.7	20.2	28.2	37.7	29.5
JRM-8 1	9/24-25	25.5	32.4	22.5	18.5	17.8	23.3
2	10/1-2	18.6	17.8	19.8	20.8	17.2	18.8
3	10/7-8	18.9	21.8	24.0	17.2	25.6	21.5
4	10/15-16	25.9	18.2	19.1	23.7	24.9	22.4
HMS-12	10/25-26	26/2	18.8	33.7	28.8	18.4	26.2
Mean		24.6	23.0	23.2	22.9	23.6	23.4

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	12.16	3.04	0.11	> 0.05
Visits	5	328.04	65.61	2.29	> 0.05
Discrepance	20	574.19	28.71		
Total	29	914.39			

This period, from August to November, marked the end of the 1951 season for the live-bait skipjack fishery of Hawaii. While our data show that the zooplankton abundance decreased considerably during these same months (fig. 12), we have no evidence that this reduction in the amount of zooplankton was a limiting factor, but rather the decline in both faunal elements may have had a common cause in some other factor of the environment.

The skipjack catch for the Territory of Hawaii for the summer of 1951 was considerably above average, whereas the catch for the 1952 season was somewhat below average and seemed particularly poor after the excellent season of the previous year.[5] Unfortunately, there were no plankton cruises during midsummer of 1952 to provide data comparable to those of 1951. Smith cruise 17, however, occurred in September 1952 during the decline of the skipjack season and provided an adjusted zooplankton mean (26.4 cc./1000 $m.^3$) not differing greatly from that of Smith cruise 10 (25.6 cc./1000 $m.^3$) of July 1951 and somewhat larger than the mean (20.3 cc./1000 $m.^3$) of Smith cruise 12 of October-November 1951. From this small amount of evidence we can conclude at least that the marked difference in skipjack catch between the 1951 and 1952 seasons was not a reflection of a corresponding reduction in zooplankton abundance.

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[4] According to Snedecor (1946) the analysis of variance is a valid test of individual and population differences if the groups of samples are randomly drawn from a normally distributed population and have similar variances. He states, however, (p. 221) "...but it has been found that little bias is introduced into the test of significance by moderately skewed distributions." Much of our plankton volume data possesses a moderate skewness which is not, in many instances, corrected by the usual logarithmic transformation. Since the distribution of the data included in table 9 was improved by a logarithmic transformation, and since the F value for visits was quite near the 0.05 level of probability, it was considered advisable to recalculate the analysis using the logarithms of the volumes. The new F values were 0.13 for stations and 2.19 for visits, which are very similar to those obtained previously and do not change our conclusions. The hypothesis that the groups have similar variances was tested by Bartlett's Test (Snedecor 1946, p. 250). The chi-square value obtained was well below the 0.05 level of probability, permitting the conclusion that the separate variances of these 6 groups do not differ sufficiently to disturb the validity of the F tests. We believe that the data in table 9 are representative of those included in the other statistical tests appearing in the report.

[5] From records supplied by the Territory of Hawaii, Division of Fish and Game the average skipjack catch for the season May to September for the 3 years 1948, 1949, and 1950 was 6,576,000 pounds. The 1951 catch for these 5 months was 11,235,000 pounds, while the 1952 catch for this same period dropped to 5,795,000 pounds.

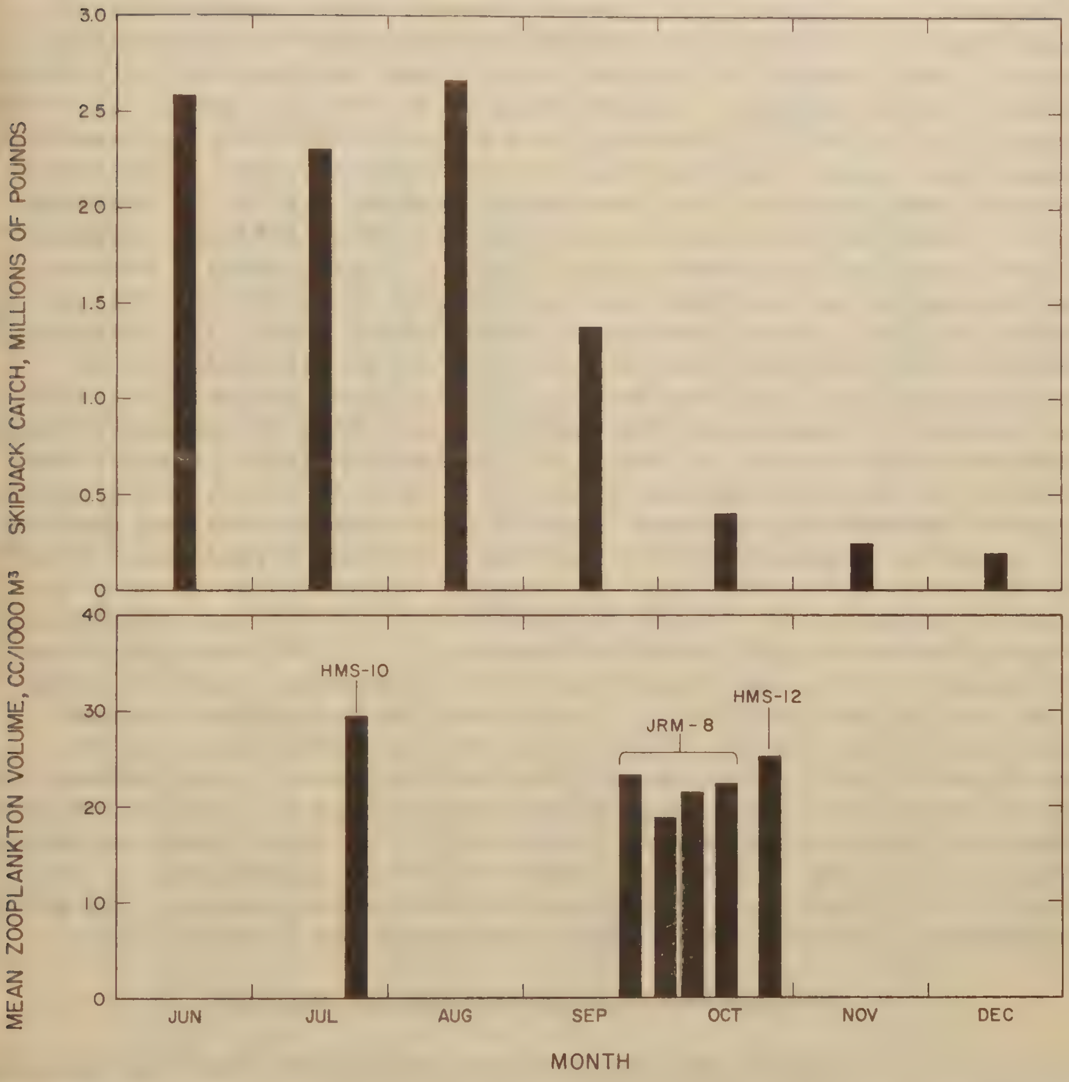


FIG. 12. VARIATIONS IN SKIPJACK CATCH AND IN ZOOPLANKTON ABUNDANCE FOR HAWAIIAN WATERS, DURING THE SUMMER AND FALL OF 1951. THE MEAN ZOOPLANKTON VOLUMES ARE FOR THE ONE SECTION LINE JUST WEST OF OAHU, WHICH WAS VISITED REPEATEDLY DURING THIS PERIOD.

To determine the variations in zooplankton abundance related to distance from land, differences between inshore and offshore areas, or between the windward and leeward sides of these oceanic islands would require a very detailed and elaborate study. An opportunity to obtain a small amount of information on these problems was afforded by cruise 9 of the Manning. Paired hauls were made at a series of 5 stations (fig. 2, part B) extending from about ½ mile from the beach--the closest the vessel could approach-- to 5 miles offshore. Two such sections were occupied, one starting in Kaneohe Bay on the windward side of Oahu and extending offshore and the other extending offshore from Waianae, on the leeward side of Oahu. Unfortunately, however, the Kaneohe series was taken during daylight hours and the Waianae series at night. Also, because of insufficient depth, the standard 200-meter oblique haul could not be employed at all stations. A stair-stepped haul from the bottom to the surface was carried out at the inshore stations where the depth was less than 200 meters. Despite these unavoidable sources of variation, rather consistent results were obtained at the two locations (fig. 13). On both series the greatest plankton volumes were secured at the 2-mile station, volumes decreased to a moderate degree in both inshore and offshore directions. Treating the data with an analysis of variance (table 10) revealed significant differences ($P < 0.05$) between the two localities, Kaneohe and Waianae, and also significant differences ($P < 0.05$) among stations. The interaction was not significant, thus indicating parallel variations for the two localities. We believe the differences between localities to be related primarily to the time of hauling and the associated diurnal variation in plankton abundance. An adjustment of the 200-meter hauls according to the usual procedure appeared to eliminate the day-night difference (table 22). The significant variation among stations may be real and related to basic differences in productivity or possibly to differences in the hauling method. No definite conclusions, however, can be drawn from these few observations.

CORRELATIONS WITH ENVIRONMENTAL FACTORS

The available hydrographic data demonstrate that the Hawaiian waters comprise a relatively homogeneous environment characterized by slight geographical variations in physical and chemical factors. Our plankton sampling indicated correspondingly uniform conditions of zooplankton abundance throughout the islands (fig. 10). Nevertheless, the authors thought it worthwhile to determine the degree of correlation of zooplankton catch and certain environmental factors considered most likely to have biological siginificance.

Surface and subsurface temperatures obtained by means of a bathythermograph were available for all seven cruises covered in this report. Three of the cruises--10, 12, and 17 of the Smith--were combined hydrographic and plankton cruises and furnished additional measurements of the environment. Inorganic phosphate analyses were

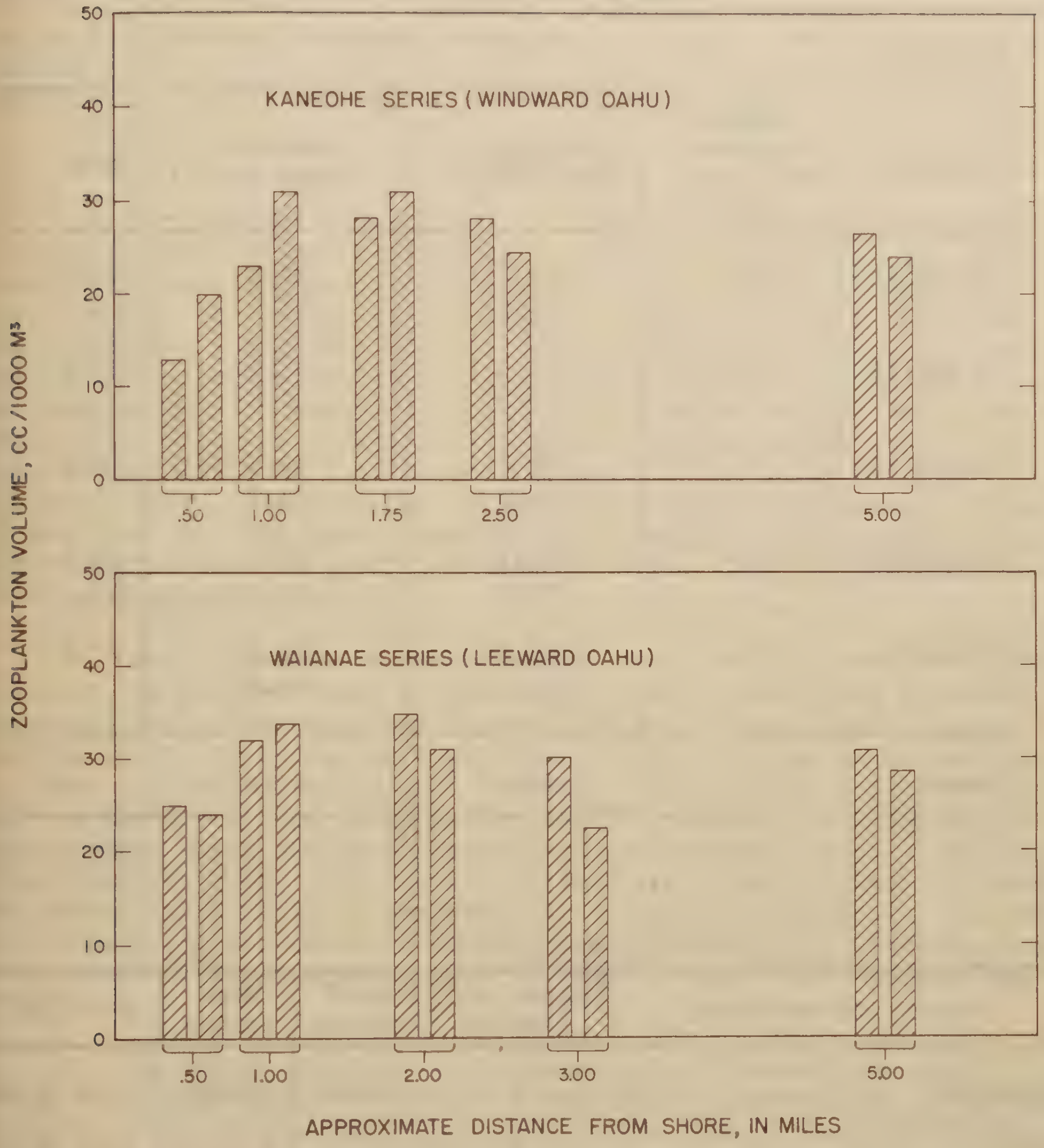


FIG. 13. ZOOPLANKTON VOLUMES ALONG TWO SERIES OF STATIONS EXTENDING FROM NEAR THE SHORELINE TO FIVE MILES OFFSHORE FROM THE ISLAND OF OAHU. THE WINDWARD SERIES WAS OCCUPIED DURING THE DAY OF NOVEMBER 18, 1951, WHILE THE LEEWARD SERIES TOOK PLACE ON THE NIGHT OF NOVEMBER 18-19, 1951, JOHN R. MANNING CRUISE 9.

Table 10. Analysis of variance of zooplankton volumes collected on cruise 9, John R. Manning; for the windward and leeward sides of the island of Oahu.

Stations	Approx. distance from shore (miles)	Windward (day hauls)	Leeward (night hauls)	Mean
7 and 12	1/2	12.8 19.9	24.8 23.9	20.4
8 and 13	1	22.9 30.9	32.1 33.8	29.9
9 and 14	2	28.2 31.1	34.7 31.0	31.2
10 and 15	3	28.1 24.6	30.2 22.4	26.3
11 and 16	5	26.6 24.1	30.8 28.6	27.5
Mean		24.9	29.2	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Localities	1	92.88	92.88*	10.07	<0.05
Stations	4	286.18	71.54*	7.76	<0.05
Locality x station interaction	4	36.89	9.22	0.82	>0.05
Within subclasses	10	112.19	11.22		
Total	19	528.14			

* Indicates a significant mean square value.

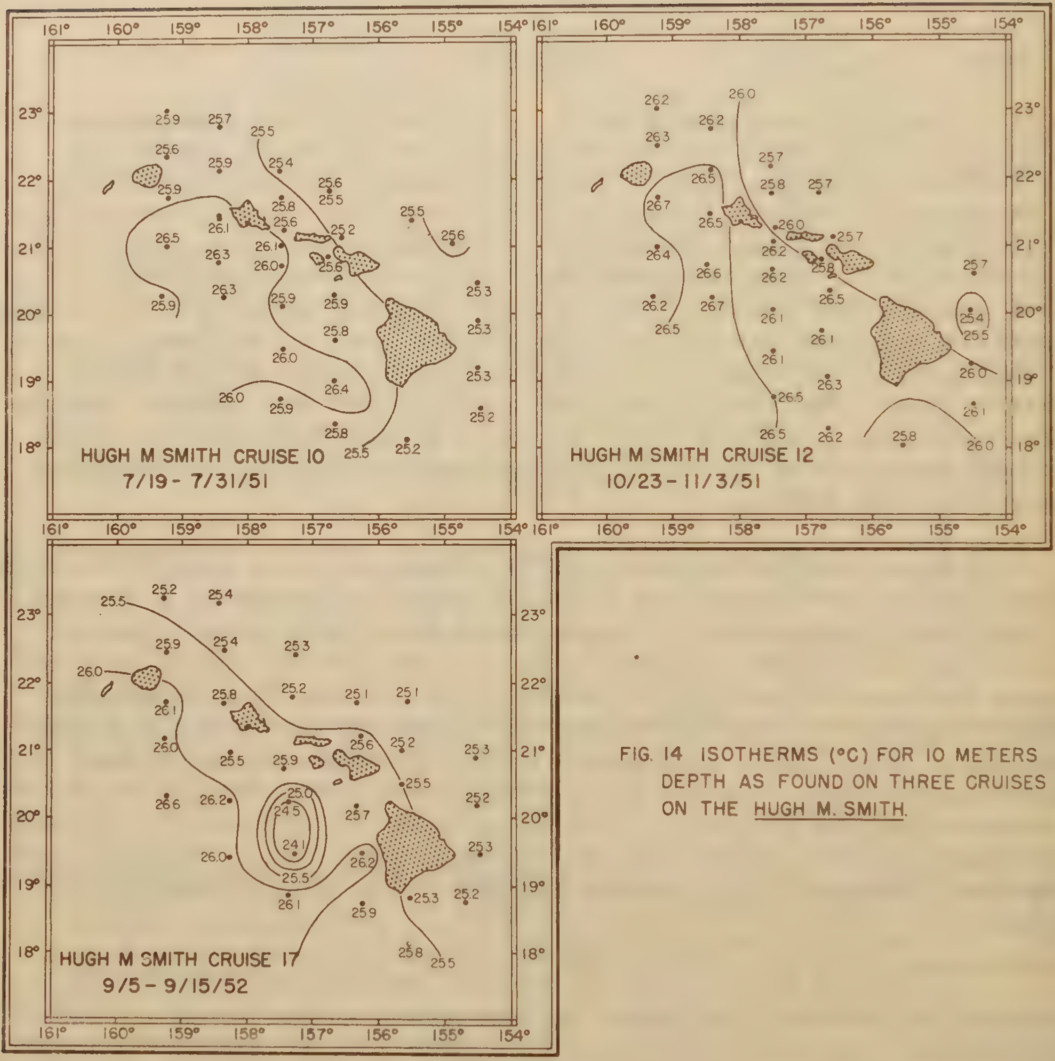
made at the 13 sample levels at each station of cruises 12 and 17. Dissolved oxygen was measured at all sample levels throughout cruise 10. Salinity and reversing thermometer data were available for all three cruises. The hydrographic data resulting from these three cruises have not as yet received thorough oceanographic study. The conclusions expressed here are based on information available at the time of this writing and are, therefore, of a preliminary nature.

Temperature

For Smith cruises 4 and 6, in May and August 1950 respectively, the deviations from the mean zooplankton volume at the 50-meter level and the ratios of 50-meter/surface zooplankton volumes were examined in respect to the depth to the top of the thermocline, the hypothesis being that a large positive deviation or a large ratio should more likely occur at stations with a shallow thermocline. A shallow thermocline would result in nutrient-rich water's being nearer the surface and more available to plant life than in the case of a deep thermocline with the discontinuity occurring below the photosynthetic zone. The results did not confirm this hypothesis. Graphs of the data (not presented here) showed a random distribution in relation to thermocline depth for both deviation from the mean and the 50-meter/surface ratios.

Since surface temperature may fluctuate as a result of diurnal heating, the authors chose the 10-meter depth as providing a temperature more truly indicative of temperature conditions in the surface layer. Figure 14 shows the isotherms for the 10-meter depth as found on three cruises of the Smith. Although conditions were remarkably uniform throughout the area, waters to the southwest held the highest temperatures while the northeastern and southeastern areas showed the lowest temperatures. Correlations between adjusted zooplankton volumes and temperatures at 10 meters were calculated for cruises 10, 12, and 17 of the Smith and cruise 8 of the Manning (table 11). For only one of the four cruises (Smith cruise 12) was a significant correlation obtained.

As stated previously, we believe that thermocline depth may have a significant influence on biological productivity. Occasionally, however, the thermal structure is such that no distinct thermocline is present or more than one gradient may be shown on the BT trace. Thus it is frequently difficult to follow set rules in designating thermocline depth and as a result the measurement tends to be rather subjective. The depth to the 70° isotherm may be more objectively read from the BT traces and, in this area of the central Pacific, falls within the thermocline and varies generally with thermocline depth. Adjusted zooplankton volumes and depth to the 70° isotherm were compared for cruises 10, 12, and 17 of the Smith and cruise 8 of the Manning (table 11). No significant correlation was found in any of the four analyses.


161° 160° 159° 158° 157° 156° 155° 154°
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HUGH M SMITH CRUISE 10
7/19 - 7/31/51
25.9 25.7 25.5 25.6 25.9 25.4 25.9 25.6 25.5 25.8 25.6 26.1 25.2 25.5 25.6 26.5 26.1 26.3 26.0 25.6 26.3 25.9 25.9 25.9 25.3 25.8 25.3 26.0 25.3 26.4 26.0 25.9 25.2 25.8 25.5 25.2
HUGH M SMITH CRUISE 12
10/23 - 11/3/51
26.2 26.0 26.2 26.3 25.7 26.5 25.8 25.7 26.7 26.5 26.0 25.7 26.4 26.2 25.8 26.6 26.2 25.7 26.5 26.2 26.7 26.1 25.4 26.5 26.1 25.5 26.1 26.0 26.3 26.5 26.1 26.5 26.2 25.8 26.0
HUGH M SMITH CRUISE 17
9/5 - 9/15/52
25.5 25.2 25.4 25.9 25.4 25.3 26.0 25.8 25.2 25.1 25.1 26.1 25.6 25.2 26.0 25.5 25.9 25.3 25.5 26.6 26.2 25.0 24.5 25.7 25.2 24.1 25.3 26.0 26.2 25.5 26.1 25.3 25.2 25.9 25.8 25.5

FIG. 14 ISOTHERMS (°C) FOR 10 METERS DEPTH AS FOUND ON THREE CRUISES ON THE HUGH M. SMITH.

Table 11. Summary of correlations of adjusted zooplankton volumes and certain physical and chemical environmental factors.

uise	X_1	X_2	Degrees of freedom	Correlation coefficient (r)	P
S-10	Zooplankton volumes (cc./1000 $m.^3$)	Temperature (°C) at 10-meter depth	32	0.263	>0.05
	"	Depth (meters) to 70° isotherm	28	0.172	>0.05
	"	Dissolved O_2 (percent saturation) at 10-meter depth	32	-0.147	>0.05
	"	Dissolved O_2 (percent saturation) at 100-meter depth	30	-0.024	>0.05
S-12	"	Temperature (°C) at 10-meter depth	28	0.453	<0.05
	"	Depth (meters) to 70° isotherm	26	0.055	>0.05
	"	Surface inorganic phosphate (μg at./L.)	28	-0.132	>0.05
S-17	"	Temperature (°C) at 10-meter depth	28	0.102	>0.05
	"	Depth (meters) to 70° isotherm	28	0.236	>0.05
	"	Surface inorganic phosphate (μ g at./L.)	28	0.506	<0.01
M-8	"	Temperature (°C) at 10-meter depth	34	-0.151	>0.05
	"	Depth (meters) to 70° isotherm	34	-0.217	>0.05

It was stated earlier (p. 30) that no significant differences were found among stations nor among visits for the zooplankton volumes obtained along the north-south section just west of Oahu during the summer and fall of 1951. For this same group of stations we employed an analysis of variance with two-way classification to examine the temperature at the 10-meter depth (table 12) and also depth to the 70° isotherm (table 13) for evidence of changes in thermal characteristics during this period of time. From the analyses we conclude that for the temperature at 10 meters there were highly significant differences ($P < 0.01$) among stations and among visits during the period of observations. The arithmetic means for visits show that the temperature of the surface layer fluctuated considerably during the period of observation. In late September the temperature was higher than in July; the cooling which took place during the first part of October was followed by a rise in late October and the highest mean of the group. The figures representing depth to 70°, however, showed no significant difference ($P > 0.05$) among stations or among visits.

The zooplankton means (table 9) show peaks in July and late October with reduced volumes in September and early October. The only justifiable conclusion appears to be that during the period from July through October 1951, which bracketed the end of the skipjack season for that year, there were significant changes in temperature in the surface layer which were not closely correlated with changes in the depth of the 70° isotherm or in the zooplankton population.

Inorganic Phosphate

On meridional sections crossing the Equator in the central Pacific we have found highly significant positive correlations between zooplankton abundance and inorganic phosphate concentrations (King and Demond 1953). We thought it of interest to investigate this relationship for the Hawaiian area. A comparison of adjusted zooplankton volumes and surface inorganic phosphate showed confusing results. On Smith cruise 12 there was no significant correlation, but on Smith cruise 17 of the following year (table 12) the correlation was highly significant. Figure 15 shows lines of equal phosphate concentration as found on these two cruises. There is no obvious pattern in the variations shown by the cruise 12 data. The cruise 17 data, however, show a definite east-west gradient of increasing phosphate values with the greatest zooplankton volumes being obtained in regions of high phosphate concentration. The mean zooplankton and phosphate values for these two cruises provide an interesting comparison (table 14). Cruise 12, in the fall of 1951, had relatively low mean values for both zooplankton and phosphate, while cruise 17, in the fall of 1952, had high values for both means.

Dissolved Oxygen

In the equatorial region of the central Pacific, where waters with reduced oxygen content occur in the region of upwelling, a significant negative correlation was found between zooplankton volumes and dissolved oxygen as percent saturation (King and Demond 1953). Oxygen and zooplankton data from Smith cruise 10 were examined for evidence of

Table 12. Analysis of variance of temperatures (in degrees centigrade) at 10-meter depth for the section of stations (numbered 6 to 10 on Smith cruise 10) as obtained on 3 cruises during the summer and fall of 1951.

Visit	Date	Station					Mean
		6	7	8	9	10	
HMS-10	7/22-24	25.7	25.9	26.1	26.3	26.3	26.06
JRM-8 1	9/24-25	25.6	26.2	26.6	26.8	26.9	26.42
2	10/1-2	25.4	25.8	26.3	26.1	26.4	26.00
3	10/7-8	25.4	26.3	26.7	25.8	26.0	26.04
4	10/15-16	25.6	26.1	26.2	26.1	25.6	25.92
HMS-12	10/25-26	26.2	26.5	26.5	26.6	26.7	26.50
Mean		25.65	26.13	26.40	26.28	26.32	

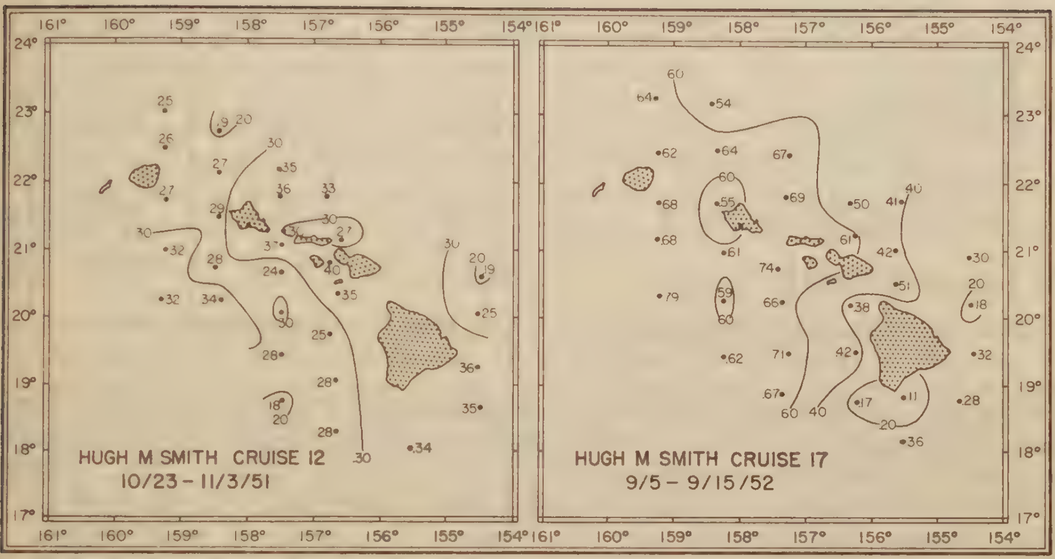
Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	2.14	0.535**	7.75	< 0.01
Visits	5	1.45	0.290**	4.20	< 0.01
Discrepance	20	1.38	0.069		
Total	29	4.97			

** Indicates a highly significant mean square value.

Table 13. Analysis of variance of depths (in meters) to the 70° isotherm for the section of stations (numbered 6 to 10 on Smith cruise 10) as obtained on 3 cruises during the summer and fall of 1951.

Visit		Date	Station					Mean
			6	7	8	9	10	
HMS-10		7/22-24	189	195	161	115	76	147.2
JRM-8	1	9/24-25	140	146	180	178	210	170.8
	2	10/1-2	96	154	172	201	168	158.2
	3	10/7-8	145	212	187	202	139	177.0
	4	10/15-16	106	126	111	134	73	110.0
HMS-12		10/25-26	148	137	148	146	146	145.0
Mean			137.3	161.7	159.8	162.7	135.3	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	4,556.8	1,139.2	1.05	> 0.05
Visits	5	14,252.6	2,850.5	2.62	> 0.05
Discrepance	20	21,733.6	1,086.7		
Total	29	40,543.0			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HUGH M SMITH CRUISE 12
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HUGH M SMITH CRUISE 17
9/5 - 9/15/52

FIG. 15. LINES OF EQUAL INORGANIC PHOSPHATE CONCENTRATION (μg at/L) FOR THE SURFACE, AS FOUND ON TWO CRUISES OF THE HUGH M. SMITH.

Table 14. Comparison of mean values of zooplankton volume, temperature at 10-meter depth, depth to the 70° isotherm, and surface inorganic phosphate for four cruises in Hawaiian waters.

Cruise	Month	Year	Zooplankton volume		Mean temp. at 10 m. (°C)	Mean depth to 70° isotherm (meters)	Mean phosphate (µgat
			Sample mean (cc./1000m.^{3})	Adjusted mean (cc./1000m.^{3})			
HMS-10	July	1951	26.0	25.6	25.8	157	--
JRM- 8	Sept., Oct.	1951	22.2	21.2	26.2	159	--
HMS-12	Oct., Nov.	1951	20.2	20.3	26.1	142	0.29
HMS-17	Sept.	1952	26.5	26.4	25.5	151	0.51

such a relationship. Correlation of zooplankton volumes resulting from 200-meter oblique hauls and percent saturation of oxygen at the 10-meter depth gave a correlation coefficient (r) of — 0.147 (table 11). Correlation of zooplankton with oxygen at 100 meters gave an "r" value of — 0.024. These coefficients are well below the level of statistical significance and indicate an almost complete lack of correlation between the two variables. The fact that negative coefficients, such as had been obtained for the equatorial region, were derived in both instances is of interest.

Temperature - Salinity Relations

Sverdrup et al. (1942, p. 740) show the Hawaiian Islands to be located near the junction of three different water masses of the central Pacific. The authors state that "....the region around the islands is a boundary region within which water masses of very different character may be encountered." One means of identifying a particular water mass is by its temperature-salinity relations or "T-S" curve.

It would seem possible that a change in plankton or pelagic fish abundance might follow a change of the water mass bathing the Islands. During the summer and fall of 1951 a significant change was noted between the zooplankton volumes collected on Smith cruise 10 in July and those of Smith cruise 12 in October. A comparison of the T-S curves for these two cruises with those shown in Sverdrup et al. (1942, p. 741), indicates that during the time of both cruises the Islands lay in the "Eastern North Pacific Central Water Mass". The change in zooplankton abundance was, therefore, not a reflection of a change in water mass as indentified by the T-S curve.

During the summer of 1952 the skipjack catch for the Hawaiian Islands was about half that of the previous summer. The zooplankton volumes on the other hand (Smith cruise 17), as previously stated, were considerably larger in the late summer than in the year before (Smith cruise 12). The T-S curve representing data collected in September 1952, on Smith cruise 17, has not yet been worked out.

COMPARISONS WITH ZOOPLANKTON ABUNDANCE OF OTHER REGIONS OF THE PACIFIC

As previously stated (p. 4), the Challenger expedition visited the Hawaiian Islands in 1875. Qualitative surface hauls were made at intervals while enroute from Japan to Hawaii and from Hawaii to Tahiti. Although apparently no measurements were made of the total numbers of organisms nor the volumes of the samples to permit detailed comparisons between areas, Tizard et al. (1885) reported that for the portion of cruise from Hawaii to Tahiti "The tow-net gatherings were very productive throughout the trip, the abundance of life in the Equatorial and Counter Equatorial Currents being very remarkable both for the number of species and individuals."

The Carnegie traversed the central Pacific during the fall of 1929. Vertical plankton hauls from depths of 100 and 150 meters were made with a ½-meter net of No. 15 silk bolting cloth. Dry weights of the plankton samples varied from 90 and 140 mg. for two stations (stations 139 and 140) about 100 miles north of the Hawaiian Islands to values as great as great as 520 mg. at about 5° N. latitude (station 155) and 450 mg. at about 2° S. latitude (Graham 1941).

During the years 1950 to 1952 quantitative zooplankton collections were obtained by the Hugh M. Smith on ten cruises in the equatorial Pacific between 120° W. and 180° W. longitude. When the resulting data are combined for this range of longitude and then separated into 5° latitudinal groups, they present the picture shown in figure 16. It is evident that within this range of latitude the greatest standing crop of zooplankton occurred in the region of the Equator. This increased productivity is the result of upwelling at the Equator associated with the equatorial divergence, which replenishes the supply of nutrients in the euphotic zone and creates especially favorable conditions for the growth of plant and animal life (Graham 1941, Sverdrup et al. 1942, Cromwell 1951, 1953, King and Demond 1953).

The amount of zooplankton in the Hawaiian area was greater than in certain regions of the North Equatorial Current (10° to 15° N. latitude and 20° to 25° N. latitude) and of the South Equatorial Current (5° to 10° S. latitude), but was distinctly less than that found in the "rich zone" from 5° S. to 5° N. latitude. We believe that these differences in zooplankton abundance are indicative of differences in basic productivity among these various regions of the central Pacific.

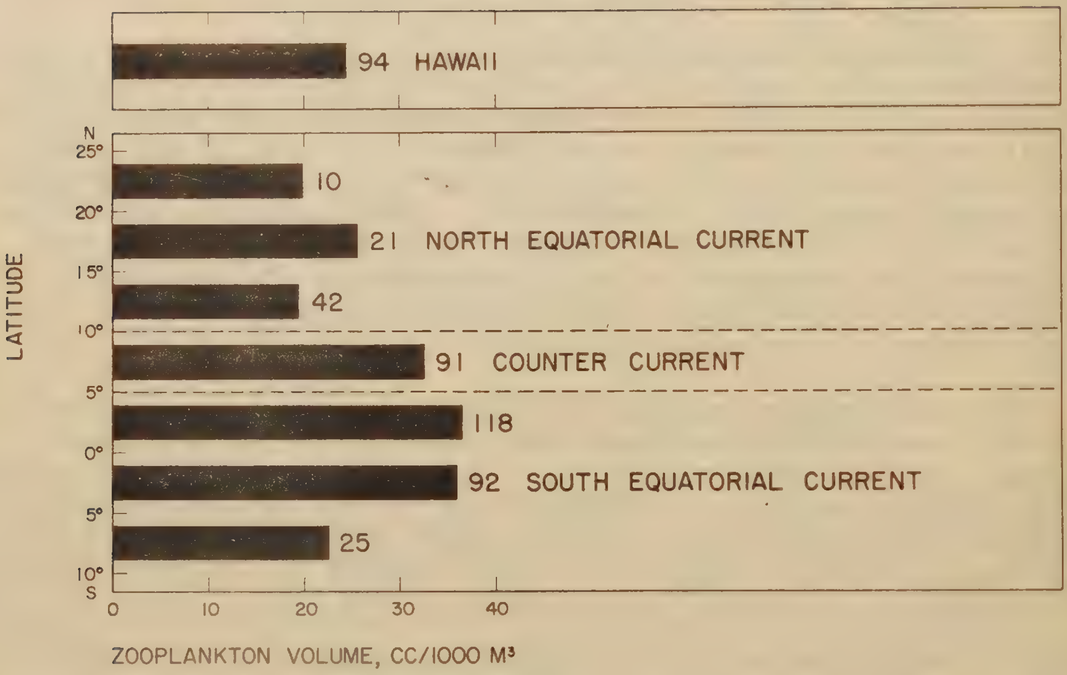

FIG. 16. COMPARISON OF ZOOPLANKTON ABUNDANCE IN DIFFERENT REGIONS AND DIFFERENT WATER MASSES OF THE CENTRAL PACIFIC. THE DATA FOR HAWAII ARE BASED ON CRUISES 10, 12, AND 17 OF THE HUGH M SMITH; THE REMAINING DATA FOR THE EQUATORIAL PACIFIC WERE DERIVED FROM SMITH CRUISES 2, 5, 7, 8, 9, 11, 14, 15, 16, AND 18. (THE NUMBER OF SAMPLES FOR EACH INTERVAL OF LATITUDE IS INDICATED FOR EACH BAR IN THE HISTOGRAM).

Some information on zooplankton concentrations in waters to the north and east of Hawaii is furnished by the Northern Holiday Expedition of Scripps Institution of Oceanography and cooperating agencies[6], conducted in August-September 1951. The resulting data may be compared with those of POFI for the Hawaiian and equatorial regions as generally similar methods were employed in making the hauls and in processing the collections. Table 15 presents data, collected on the westernmost stations of the expedition, which indicate in general a marked increase in zooplankton concentration with increasing latitude. Two chief differences are apparent between these data and those for the Hawaiian areas: (1) the latitudinal means for the Northern Holiday Expedition are, with one exception (35° 00' - 39° 59' N. latitude), considerably larger, and (2) there is a much greater variation among the individual volumes than appears in the Hawaiian samples. We believe that this high variation among plankton volumes taken within a relatively short interval of space and time is particularly characteristic of temperate and higher latitudes and is not found to such an extent, as indicated by our data, in the tropics and subtropics.

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[6] The plankton collections were processed by Dr. E. H. Ahlstrom and staff, South Pacific Investigations, Fish and Wildlife Service, and were made available to the authors through the courtesy of Dr. Ahlstrom.

Table 15. Zooplankton volumes (cc./1000 m.^{3}) arranged to show variation with latitude, as obtained on the Northern Holiday Expedition[1] to the northeastern Pacific in August-September 1951. Only volumes obtained on the western portion of the cruise between 145° and 160° W. longitude were included in the table.

	Latitudes						
	25° 00'- 29° 59'N	30° 00'- 34° 59'N	35° 00'- 39° 59'N	40° 00'- 44° 59'N	45° 00'- 49° 59'N	50° 00'- 54° 59'N	55°00'- 59°59'N
	467[2]	15	6	32	180	242	241
	43	41	44	14	85	75	235
	39	49	7	76	117	92	
		42		55	104	147	
				32	122	83	
				75	155	39	
				54		111	
				77		60	
				33		151	
				32		61	
						21	
						60	
Mean	41.0	36.8	19.0	48.0	127.2	95.2	238.0

[1] This expedition was sponsored by the Scripps Institution of Oceanography and collaborating agencies. The zooplankton collections were processed by Dr. E H. Ahlstrom and staff of the South Pacific Investigations, Fish and Wildlife Service. These data, previously unpublished, were made available to the authors through the courtesy of Dr. Ahlstrom and Mr. Warren Wooster of the Scripps Institution of Oceanography.

[2] This sample was reported (Ahlstrom) to consist primarily of salps; therefore, we choose to omit it from this comparison of latitudinal variation.

SUMARY AND CONCLUSIONS

1. This report presents an analysis of 365 quantitative zooplankton collections obtained on seven cruises in Hawaiian waters during the years 1950 to 1952.

2. The collections were taken by a variety of hauling methods: horizontal hauls at several depths ranging from the surface to 300 meters, and oblique hauls to depths of 200, 300, and 500 meters.

3. One type of net was used throughout, a 1-meter net with body of 30XXX grit gauze, rear section and bag of 56XXX. The net was equipped with a flow meter which gave an estimate of the volume of water strained.

4. In the laboratory the displacement volumes of all samples were measured in uniform fashion. For each sample there was calculated the volume of the more nutritious zooplankton per unit of water strained.

5. For the two cruises employing horizontal hauls, the greatest zooplankton volumes occurred on the average at the 50-meter level in both day and night samples.

6. A 24-hour series of successive oblique hauls to 200, 300, and 500 meters showed significant differences among depths and among hauling times. A marked diurnal variation in catch was found among hauls to all three depths.

7. A method is presented for adjusting the zooplankton volumes for differences associated with diurnal variations in the catch. The method is based upon the similarity between diurnal variation in zooplankton abundance in the upper 200 meters and the curve of the sine function, with midnight equated to the angle whose sine is + 1.0.

8. Geographically the abundance of zooplankton was remarkably uniform throughout the Islands. On the average, however, the southeastern region, i.e. waters adjacent to the island of Hawaii yielded the lowest zooplankton volumes.

9. For the years 1950 and 1951 zooplankton samples collected in early and midsummer, during the skipjack season, were significantly larger than those taken in the late summer and fall after the close of the season. This decrease in the amount of zooplankton may bear some direct or indirect influence on the exodus of skipjack from Hawaiian waters, although the decrease was certainly not of sufficient degree to be a major or determining factor.

10. In a preliminary sampling experiment no significant differences in zooplankton abundance were found between the coastal waters of windward and leeward Oahu; differences were found, however, on both sides of the island among a series of stations extending from close to the shoreline to 5 miles offshore.

11. In only one of four cruises tested was there a significant correlation between zooplankton volumes and temperatures at a depth of 10 meters.

12. No significant correlation was found between zooplankton volumes and depth to the 70° isotherm for any of the four cruises tested.

13. During the late summer and fall of 1951 there were statistically significant changes in temperature at the 10-meter depth along a north-south section just west of Oahu which were not accompanied by any significant change in zooplankton concentration.

14. A comparison of zooplankton volumes and surface inorganic phosphate showed no significant correlation for Smith cruise 12, but a highly significant correlation for Smith cruise 17.

15. Correlations of zooplankton volume and dissolved oxygen as percent saturation at the 10-meter and the 100-meter depths gave low negative coefficients of no statistical significance.

16. An examination of temperature-salinity relations indicated that during July and October, 1951, the water surrounding the Hawaiian Islands yielded T-S curves characteristic of the "Eastern North Pacific Central Water Mass." The change in zooplankton abundance between the summer and fall conditions in 1951 was therefore not a reflection of a change of water mass.

17. In view of the uniformity in the amount of zooplankton and in the properties of the sea water forming its environment, it is not surprising that we found few instances of correlations with these properties. The few significant correlations that did occur are noteworthy, however, and suggest the idea that zooplankton and these factors are not directly related but are all governed by some as yet unexplained condition in the environment that is more fundamental and more variable than the temperature or the phosphate itself.

18. During the period of observation the amount of zooplankton in Hawaiian waters was greater than in the North Equatorial Current south of the Islands, but distinctly less than that found near the Equator from 5° N. to 5° S. latitude. Data from the Northern Holiday Expedition of Scripps Institution of Oceanography and collaborating agencies provide evidence that zooplankton increases markedly in abundance to the north and northeast of the Islands, reaching concentrations at 50° to 60° N. latitude several times those found near Hawaii and in the rich zone near the Equator.

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APPENDIX

Table 16. Zooplankton volumes collected on cruise 4, *Hugh M. Smith*, May 1950. All hauls were horizontal tows at the depth indicated (plus or minus up to 20 percent for the deeper hauls).

Station	Sample	Position		Date	Time[1]	Depth of haul, meters	Water strained in m.^{3}	Zooplankt cc./1000m
		North latitude	West longitude					
1	1	23°31'	161°07'	5/16/50	0934-1031	0	2255.3	10.7
1	2	"	"	"	0928-1045	50	2466.7	22.3
1	3	"	"	"	0921-1054	150	3168.1	8.3
1A	1	22°40'	161°15'	5/16/50	1722-1819	0	2604.7	25.7
1A	2	"	"	"	1716-1828	50	1956.3	22.3
1A	3	"	"	"	1710-1833	150	2060.7	10.8
2	2	21°52.5'	161°07'	5/17/50	0106-0224	100	2523.7	9.4
2	3	"	"	"	0100-0239	200	2347.2	13.3
2	4	"	"	"	0240-0341	0	2504.5	25.0
3	1	21°06'	161°05.5'	"	0925-1026	0	2699.9	2.3
3	2	"	"	"	0920-1031	50	2603.4	23.1
3	3	"	"	"	0913-1038	150	3364.7	3.7
4	1	20°14.5'	161°07.5'	"	1640-1741	0	2124.9	9.4
4	2	"	"	"	1635-1745	100	2229.0	10.1
4	3	"	"	"	1630-1750	200	2670.9	6.1
5	1	19°23.8'	161°06.3'	5/18/50	0028-0130	0	2231.5	21.5
5	2	"	"	"	0021-0136	50	2589.5	28.0
5	3	"	"	"	0015-0141	150	3494.0	7.9
6	1	19°25'	159°50'	"	1048-1148	0	2271.9	1.2
6	2	"	"	"	1040-1154	100	3392.9	6.0
6	3	"	"	"	1030-1201	200	3991.6	4.3
7	1	20°14.5'	159°50'	"	1835-1937	0	2967.4	142.3
7	2	"	"	"	1831-1941	50	2318.7	10.6
7	3	"	"	"	1825-1946	150	2633.4	6.7
8	1	21°05'	159°50'	5/19/50	0255-0357	0	2472.3	20.6
8	2	"	"	"	0250-0403	100	2321.9	17.0
8	3	"	"	"	0245-0408	200	2860.7	7.9
9	1	21°47.7'	159°51'	"	1000-1101	0	2585.2	4.9
9	2	"	"	"	0953-1107	50	2714.2	16.2
9	3	"	"	"	0945-1114	150	3865.7	5.5
10	1	22°40'	159°50	5/15/50	1456-1557	0	2742.2	5.1
10	2	"	"	"	1448-1623	100	4104.8	25.7
10	3	"	"	"	1440-1632	200	4560.7	6.5
11	1	23°30'	159°50	5/15/50	2316-0018	0	2704.2	44.6
11	2	"	"	"	2308-0022	50	2996.1	23.5
11	3	"	"	"	2300-0033	150	3541.9	8.5
12	1	22°40'	158°30'	"	0503-0604	0	2642.3[2]	35.3
12	2	"	"	"	0453-0612	100	3068.8	16.0
12	3	"	"	"	0445-0622	200	--	--

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[1] Local civil time corresponding to + 10 zone time.

[2] Based on a calculated meter reading derived from average performance of current meter at similar vessel speed.

able 16. (Cont'd)

n	Sample	Position		Date	Time 1/	Depth of haul, meters	Water strained in m.^{3}	Zooplankton cc./1000m.^{3}
		North latitude	West longitude					
3	1	21°51'	158°29'	5/21/50	0150-0254	0	2906.2	29.3
3	2	"	"	"	0146-0307	100	2763.8	27.0
3	3	"	"	"	0140-0308	150	3033.6	10.0
3	4	21°45.5'	158°29'	"	0320-0425	50	2561.0	28.6
4	1	20°58'	158°26'	"	0950-1123	200	4334.0	3.2
4	2	"	"	"	0957-1117	100	3181.6	13.0
4	3	"	"	"	1005-1105	0	2265.3	9.6
5	1	20°12.3'	158°30'	"	1610-1713	0	2950.2	10.0
5	2	"	"	"	1605-1718	50	3033.6	16.6
5	3	"	"	"	1600-1724	150	3383.2	5.5
6	1	19°22'	158°28'	5/21/50	2253-2357	0	3017.4	14.8
6	2	"	"	"	2246-2404	100	3178.6	15.6
6	3	"	"	"	2239-2410	200	3975.3	6.2
7	1	18°32.5'	158°27.8'	5/22/50	0546-0648	0	2594.0	22.2
7	2	"	"	"	0541-0652	50	1444.3 3/	20.2 3/
7	3	"	"	"	0535-0700	150	3652.4	4.1
8	1	18°32'	157°05'	5/22/50	1531-1634	0	2768.9	2.2
8	2	"	"	"	1526-1645	100	3023.6	11.0
8	3	"	"	"	1520-1650	200	3433.8	5.6
9	1	19°24.3'	157°10'	5/23/50	0018-0119	0	3097.3	19.5
9	2	"	"	"	0013-0124	50	2010.3	36.2
9	3	"	"	"	0006-0131	150	2451.6	7.5
0	1	20°14'	157°03.5'	"	0911-1016	0	3346.3	4.0
0	2	"	"	"	0905-1022	100	2741.2	9.5
0	3	"	"	"	0859-1028	200	2758.6	8.0
1	1	20°58.7'	157°10.2'	"	1648-1749	0	2739.9	9.6
1	2	"	"	"	1641-1757	50	2284.7	31.5
1	3	"	"	"	1635-1803	150	2825.5	7.0
2	1	21°53'	157°08.5'	5/24/50	0120-0220	0	2705.6	30.0
2	2	"	"	"	0116-0227	100	2262.1	17.5
2	3	"	"	"	0110-0233	200	2544.8	10.0
3	1	22°40'	157°10'	5/14/50	1852-1952	0	2191.5	43.9
3	2	"	"	"	1845-1958	50	2419.9	27.1
3	3	"	"	"	1837-2004	150	3030.9	9.1
4	1	22°45'	155°49'	"	0820-0915	0	1254.7	29.5
4	2	"	"	"	0815-0931	100	2231.8	10.4
4	3	"	"	"	0807-0939	200	2971.0	8.1
5	1	21°54'	155°48.2'	5/24/50	1333-1434	0	2644.7	5.3
5	2	"	"	"	1330-1439	50	2275.0	23.4
5	3	"	"	"	1325-1445	150	2773.5	3.5
6	1	21°02.5'	155°45.5'	"	2107-2208	0	2815.1	22.1

3/ Gear fouled; questionable meter reading and zooplankton volume.

Table 16. (Cont'd)

Sta-tion	Sample	Position		Date	Time1/	Depth of haul, meters	Water strained in m.3	Zooplan cc./100
		North latitude	West longitude					
26	2	21°02.5'	155°45.5'	5/24/50	2101-2213	100	2263.7	18.6
26	3	"	"	"	2055-2218	200	2631.1	6.0
27	1	20°30'	155°45'	5/25/50	0214-0314	0	3098.8	23.8
27	2	"	"	"	0208-0320	50	2786.9	22.2
27	3	"	"	"	0200-0326	150	3069.5	8.9
28	1	18°33.5'	155°48'	"	1740-1844	0	3169.4	16.4
28	2	"	"	"	1735-1850	100	2404.0	7.4
28	3	"	"	"	1730-1855	200	2787.0	5.5

able 17. Zooplankton volumes collected on cruise 6, Hugh M. Smith, August 1950. All hauls were horizontal tows at the depth indicated (plus or minus up to 20 percent for the deeper hauls).

n	Sample	Position		Date	Time[1]	Depth of haul, meters	Water strained in m.^{3}	Zooplankton cc./1000m.^{3}
		North latitude	West longitude					
1	1	23°30'	161°05.5'	8/25/50	1417-1518	0	2046.6	5.2
1	2	"	"	"	1412-1523	50	1993.3	13.9
1	3	"	"	"	1405-1531	150	3143.3	5.6
1A	1	22°45'	161°15'	"	2048-2148	0	2634.5	8.1
1A	2	"	"	"	2040-2155	50	2810.6	27.0
1A	3	"	"	"	2030-2206	150	3316.3	7.3
2	1	21°57'	161°05'	8/26/50	0331-0433	0	2255.7	7.4
2	2	"	"	"	0323-0441	100	3069.2	19.0
2	3	"	"	"	0315-0449	200	4007.6	7.0
3	1	21°09.5'	161°03'	"	1057-1158	0	2149.8	2.4
3	2	"	"	"	1052-1203	50	2067.7	11.8
3	3	"	"	"	1042-1211	150	2595.6	3.0
4	1	20°20'	161°05'	"	1809-1910	0	2251.3	8.8
4	2	"	"	"	1801-1918	100	2795.5	8.4
4	3	"	"	"	1750-1927	200	3566.6	6.1
5	1	19°25.5'	161°05'	8/27/50	0108-0210	0	2309.5	7.4
5	2	"	"	"	0055-0222	150	3112.2	12.8
5	3	"	"	"	0042-0232	300	3701.0	6.0
6	1	19°26'	159°50'	"	1007-1108	0	2392.6	4.8
6	2	"	"	"	0958-1116	100	2482.6	9.4
6	3	"	"	"	0950-1126	200	3982.7	7.8
7	1	20°16.5'	159°44'	"	1911-2012	0	3033.6	16.5
7	2	"	"	"	1903-2024	50	3220.6	14.5
7	3	"	"	"	1853-2036	150	4295.8	8.7
8	1	20°54'	159°47'	8/28/50	0527-0628	0	2840.4	14.8
8	2	"	"	"	0516-0639	100	2665.7	12.8
8	3	"	"	"	0507-0647	200	3684.0	10.2
9	1	21°50.1'	159°50.5'	"	1403-1507	0	2456.3	4.3
9	2	"	"	"	1358-1512	50	2486.8	10.2
9	3	"	"	"	1350-1520	150	3061.5	5.5
10	1	22°48.5'	159°51'	8/24/50	2307-0011	0	2334.5	11.4
10	2	"	"	"	2253-0031	150	3609.3	15.3
10	3	"	"	"	2239-0041	300	5799.4	7.3
11	1	23°27'	159°45.7'	8/25/50	0517-0617	0	2373.9	17.9
11	2	"	"	"	0510-0624	50	2847.2	14.2
11	3	"	"	"	0500-0633	150	4214.0	8.8
12	1	22°43.3'	158°26'	8/24/50	1314-1415	0	2706.0	3.7
12	2	"	"	"	1302-1424	100	2900.5	11.1
12	3	"	"	"	1250-1432	200	3951.4	5.9

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[1] Local civil time corresponding to + 10 zone time.

Table 17. (Cont'd)

Station	Sample	Position		Date	Time1/	Depth of haul, meters	Water strained in m.3	Zooplank cc./100
		North latitude	West longitude					
13	1	21°50'	158°30.6'	8/24/50	0541-0643	0	2007.5	42.6
13	2	"	"	"	0536-0649	50	3137.8	29.0
13	3	"	"	"	0528-0657	150	3564.4	9.0
14	1	20°50'	158°32'	8/18/50	1730-1830	0	2286.6	11.2
14	2	"	"	"	1725-1838	100	2173.1	10.1
14	3	"	"	"	1720-1844	200	2250.1	6.9
15	1	20°15'	158°24'	8/19/50	0004-0108	0	2717.6	19.6
15	2	"	"	"	2352-0121	150	3807.3	21.0
15	3	"	"	"	2340-0132	300	5280.2	11.4
16	1	19°24'	158°23'	8/19/50	0810-0911	0	3380.4	7.4
16	2	"	"	"	0759-0922	100	3484.3	7.5
16	3	"	"	"	0750-0930	200	3064.9	8.6
17	1	18°30'	158°29'	"	1536-1636	0	2239.5	2.0
17	2	"	"	"	1528-1649	100	3314.6	15.0
17	3	"	"	"	1522-1654	150	4090.8	4.0
18	1	18°22'	157°07.5'	8/20/50	0239-0341	0	1609.4	36.8
18	2	"	"	"	0228-0351	100	2430.1	24.0
18	3	"	"	"	0210-0356	200	3608.6	11.7
19	1	19°31'	157°10'	"	2329-0030	0	2727.9	23.6
19	2	"	"	"	2317-0040	100	3929.9	20.6
19	3	"	"	"	2311-0045	150	4781.8	13.3
20	1	20°23'	157°07'	8/21/50	0859-1000	0	2112.4	3.5
20	2	"	"	"	0842-1011	150	3147.3	10.5
20	3	"	"	"	0815-1021	300	4289.0	7.6
21	1	20°55.5'	157°10.3'	8/21/50	1426-1527	0	2767.3	14.1
21	2	"	"	"	1418-1533	100	2447.1	6.9
21	3	"	"	"	1412-1537	150	2806.2	7.1
22	1	21°50'	157°10.5'	8/23/50	1810-1911	0	2586.4	88.3
22	2	"	"	"	1802-1920	100	3070.2	12.9
22	3	"	"	"	1754-1928	200	4067.0	8.7
23	1	22°39'	157°13'	"	1038-1138	0	2840.8	1.9
23	2	"	"	"	1030-1144	50	2990.0	12.0
23	3	"	"	"	1020-1154	150	3640.0	5.4
24	1	22°40'	155°47'	8/22/50	2212-2313	0	2903.5	17.1
24	2	"	"	"	2201-2324	100	3338.2	31.2
24	3	"	"	"	2149-2334	200	5030.5	11.3
25	1	21°56.3'	155°45.3'	"	1519-1620	0	2815.6	4.8
25	2	"	"	"	1510-1633	150	3431.8	8.5
25	3	"	"	"	1500-1644	300	3916.6	8.9
26	1	21°03.5'	155°50'	"	0728-0830	0	2107.3	14.0
26	2	"	"	"	0720-0840	100	3071.7	8.6
26	3	"	"	"	0711-0850	200	4688.0	5.2
27	1	20°30'	155°47.2'	"	0152-0253	0	2178.2	25.7
27	2	"	"	"	0148-0258	50	2305.0	25.6
27	3	"	"	"	0140-0304	150	3884.7	7.2
28	1	18°32.5'	156°07'	8/20/50	1157-1256	0	2219.6	3.2
28	2	"	"	"	1145-1303	100	2578.0	21.9
28	3	"	"	"	1136-1307	200	4080.2	7.1

le 18. Zooplankton volumes collected on cruise 10, Hugh M. Smith, July 1951. All hauls were oblique tows to 200 meters depth except at stations 15 and 21 located in shoal water.

Station	Position		Date	Time[1]	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
	North latitude	West longitude				Sample volume	Adjusted volume
1	20°18'	159°19.5'	7/21/51	0907-0940	1404.1	31.8	38.7
2	21°02.5'	159°14'	7/21/51	1753-1828	1754.2	19.1	18.7
3	21°44'	159°13'	7/21/51	2352-0020	1396.0	28.5	22.0
4	22°22'	159°15'	7/22/51	0715-0752	1600.1	20.6	23.0
5	23°02'	159°15'	7/22/51	1354-1419	1244.6	49.2	61.7
6	22°48'	158°24.5'	7/22/51	2215-2240	1336.2	41.2	32.6
7	22°08'	158°24'	7/23/51	0428-0505	2076.4	31.4	28.7
8	21°29'	158°25'	7/23/51	1125-1159	1946.3	15.6	20.2
8A	21°26.5'	158°24'	7/19/51	1427-1502	1896.5	27.1	33.0
9	20°50'	158°25'	7/23/51	2330-0000	1040.8	36.5	28.2
10	20°17'	158°21.5'	7/24/51	0608-0641	1683.5	36.8	37.7
11	18°45'	157°30'	7/24/51	2122-2157	1887.7	27.3	22.1
12	19°32'	157°28'	7/25/51	0508-0539	1866.0	15.5	14.8
13	20°07'	157°28'	7/25/51	1052-1125	1450.7	12.5	16.1
14	20°43'	157°29'	7/25/51	1617-1650	1874.0	13.0	14.2
15[2]	21°02.5'	157°29'	7/25/51	1934-2004	1276.6	38.9	34.8
16	21°17'	157°26'	7/25/51	2302-2335	1872.7	26.4	20.5
17	21°44.5'	157°29'	7/26/51	0407-0439	1532.8	33.1	29.6
18	22°08.5'	157°32'	7/26/51	0913-0945	1595.6	20.6	25.1
19	21°51'	156°45'	7/26/51	1744-1819	1848.3	21.3	21.3
20	21°10'	156°35'	7/27/51	0000-0030	1666.1	41.8	32.3
21[3]	20°50	156°45'	7/27/51	0358-0429	2013.4	11.9	10.7
22	20°20'	156°39.5'	7/27/51	0915-0947	1937.5	17.5	21.6
23	19°37.5'	156°40'	7/27/51	1457-1530	1662.6	18.8	22.2
24	19°01.5'	156°40'	7/27/51	2020-2050	1355.6	47.2	39.9
25	18°22'	156°40'	7/28/51	1039-1109	1557.4	13.4	17.2
26	18°10'	155°35'	7/28/51	2120-2150	1454.3	24.1	19.5
27	18°37'	154°26.5'	7/29/51	0955-1027	1284.4	11.0	13.9
28	19°13.5'	154°30'	7/29/51	1405-1437	1851.1	16.6	20.5
29	19°54.5'	154°29'	7/29/51	2008-2038	1342.7	20.5	17.7
30	20°30'	154°30'	7/30/51	0153-0224	1535.6	22.7	18.1
31	21°05.5'	154°53.5'	7/30/51	0740-0810	1482.5	35.7	40.6
32	21°25'	155°30'	7/30/51	1343-1414	1721.1	20.9	26.2
33	21°51'	156°45'	7/30/51	2340-0011	1690.9	35.4	27.3

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[1] Local civil time corresponding to + 10 zone time.

[2] Stair-stepped oblique haul to 40 meters depth.

[3] " " " " " 30 meters depth.

Table 19. Zooplankton volumes collected on cruise 12, *Hugh M. Smith*, Oc November 1951. All hauls were oblique tows to 200 meters dep except at stations 15 and 21 located in shoal water.

Station	Position		Date	Time[1]	Water strained in m.^{3}	Zooplankton cc./1000 m.	
	North latitude	West longitude				Sample volume	Adjuste volum
1	20°18'	159°18'	10/24/51	0413-0454	2804.6	37.0	33.6
2	21°01'	159°14'	10/24/51	1152-1222	1857.8	20.3	27.0
3	21°46'	159°12'	10/24/51	2119-2156	1984.3	24.9	19.7
4	22°28'	159°14'	10/25/51	0214-0242	1580.9	27.7	21.9
5	23°02'	159°15'	10/25/51	0817-0845	1345.5	19.6	23.5
6	22°46'	158°25'	10/25/51	1552-1628	2251.0	23.3	26.2
7	22°09'	158°24'	10/25/51	2244-2314	1389.2	24.8	18.8
8	21°30'	158°26'	10/26/51	0515-0549	2121.9	34.6	33.7
9	20°46'	158°28'	10/26/51	1155-1225	1425.7	21.7	28.8
10	20°17.5'	158°22'	10/26/51	1733-1806	1947.3	18.0	18.4
11	18°47'	157°27'	10/27/51	0810-0838	1249.5	20.5	24.2
12	19°28.5'	157°27'	10/27/51	1520-1548	2088.5	19.6	23.1
13	20°06'	157°28'	10/27/51	2222-2258	2191.6	26.2	20.1
14	20°40'	157°28'	10/28/51	0527-0602	2257.6	20.6	20.1
15[2]	21°05'	157°28'	10/28/51	1032-1058	1497.3	13.0	17.0
16	21°17'	157°25'	10/28/51	1249-1319	2076.1	10.9	14.3
17	21°48'	157°29'	10/28/51	1826-1856	1492.0	22.5	21.4
18	22°12'	157°31'	10/28/51	2339-0009	1410.7	22.3	16.8
19	21°50'	156°47'	10/29/51	0725-0759	2179.0	13.7	15.5
20	21°09.5'	156°35'	10/29/51	1350-1421	2283.9	12.9	16.5
21[3]	20°49'	156°45'	10/29/51	1745-1813	1594.3	21.6	21.8
22	20°22'	156°39'	10/29/51	2245-2317	1409.7	18.8	14.3
23	19°44'	156°44'	10/30/51	0632-0710	2424.9	13.6	14.7
24	19°04'	156°38'	10/30/51	1520-1552	1849.7	19.0	22.4
25	18°21'	156°38.5'	10/30/51	2223-2255	1586.4	26.7	20.5
26	18°03'	155°33'	10/31/51	0737-0809	1393.6	11.8	13.6
27	18°39.5'	154°28'	10/31/51	1730-1803	1669.8	14.2	14.6
28	19°16.5'	154°32'	10/31/51	2323-2357	1399.7	22.4	15.9
29	20°04'	154°33'	11/1/51	0615-0648	1791.3	15.7	16.5
30	20°37.5'	154°28'	11/1/51	1126-1158	1652.4	9.3	12.3

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[1] Local civil time corresponding to + 10 zone time.

[2] Stair-stepped oblique haul to 35 meters depth.

[3] " " " " " 25 meters depth.

Table 20. Zooplankton volumes collected on cruises 17, Hugh M. Smith September 1952. All hauls were oblique tows to 200 meters depth.

ion	Position		Date	Time[1]	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
	North latitude	West longitude				Sample volume	Adjusted volume
1	20°20'	159°14'	9/6/52	0314-0344	--	--	--[2]
2	21°11'	159°17'	9/6/52	1010-1047	2009.1	25.0	31.0
3	21°43'	159°16'	9/6/52	1535-1606	1340.5	24.4	27.5
4	22°27.5'	159°15'	9/6/52	2221-2251	1330.3	37.7	30.1
5	23°14	159°18'	9/7/52	0519-0554	1728.0	29.7	29.1
6	23°09'	158°26'	9/7/52	1222-1253	1614.9	23.5	29.7
7	22°30'	158°20'	9/7/52	1810-1841	1488.7	23.6	23.1
8	21°42.5'	158°20'	9/8/52	0106-0139	1738.1	31.0	24.8
9	20°58'	158°14'	9/8/52	1136-1205	1357.5	19.1	24.3
10	20°16'	158°15'	9/8/52	1740-1811	1401.7	25.5	25.5
11	19°26'	158°15'	9/9/52	0011-0042	1643.3	41.0	32.4
12	18°52'	157°21'	9/9/52	0922-0950	1312.3	22.3	27.1
13	19°29'	157°15.5'	9/9/52	1507-1540	1716.4	20.1	23.4
14	20°15'	157°22'	9/9/52	2136-2214	2252.6	31.9	26.0
15	20°43'	157°26'	9/10/52	0313-0346	1614.6	37.0	31.8
16	21°47.5'	157°18'	9/10/52	1149-1216	1109.8	31.2	39.6
17	22°26'	157°16'	9/10/52	1802-1835	1631.9	24.9	24.4
18	21°45'	156°20'	9/11/52	0308-0340	1365.7	47.2	40.6
19	21°17'	156°15.5'	9/11/52	0835-0908	1450.6	20.8	24.6
20	21°02'	155°37'	9/11/52	1432-1503	1583.5	17.4	20.9
21	20°28.5'	155°37'	9/11/52	1930-2002	1679.4	35.0	31.7
22	20°12'	156°19'	9/12/52	0152-0228	1587.2	22.9	18.9
23	19°30'	156°15'	9/12/52	0759-0830	2326.2	21.3	24.4
24	18°46'	156°14'	9/12/52	1401-1434	1732.7	19.0	23.1
25	18°10'	155°33'	9/12/52	2212-2245	1408.1	31.0	25.0
26	18°49'	155°32'	9/13/52	0421-0453	1497.3	22.2	20.4
27	18°46'	154°39'	9/13/52	1155-1226	1545.7	19.1	24.2
28	19°30'	154°26'	9/13/52	1828-1900	1408.9	24.6	23.6
29	20°13'	154°28'	9/14/54	0112-0142	1667.0	25.6	20.5
30	20°54'	154°30'	9/14/52	0740-0814	1615.4	20.9	23.6
31	21°44'	155°34'	9/14/52	1750-1820	1517.1	20.2	20.2

1/ Local civil time corresponding to + 10 zone time.

2/ Sample lost at sea as result of torn net.

Table 21. Zooplankton volumes collected on cruise 8, John R. Manning. All hauls were oblique tows to 200 meters depth.

Station	Position		Date	Time[1]	Water strained in m.³	Zooplankton cc./1000 m.³	
	North latitude	West longitude				Sample volume	Adjuste volume
1	22°48'	158°25'	9/24/51	0640-0654	1653.4	24.0	25.5
2	22°27'	158°25'	9/24/51	0930-1005	1328.2	22.7	30.1
3	22°09'	158°25'	9/24/51	1217-1253	1556.9	23.1	32.4
4	21°47'	158°25'	9/24/51	1506-1545	1585.9	17.5	21.0
5	21°27'	158°25'	9/24/51	1837-1918	1989.9	24.6	22.5
6	21°07'	158°25'	9/24/51	2132-2210	1964.6	34.1	25.4
7	20°47'	158°25'	9/25/51	0021-0100	1608.8	25.9	18.5
8	20°27'	158°25'	9/25/51	0305-0343	1549.3	28.0	22.4
9	20°06'	158°25'	9/25/51	0606-0642	1510.5	17.3	17.8
15	22°48'	158°25'	10/1/51	0204-0240	1427.1	24.6	18.6
16	22°28'	158°25'	10/1/51	0455-0537	1618.0	25.5	24.0
17	22°08'	158°25'	10/1/51	0741-0816	1632.1	15.0	17.8
18	21°48'	158°25'	10/1/51	1026-1054	1280.4	14.6	20.1
19	21°27.5'	158°25'	10/1/51	1430-1508	1931.6	15.2	19.8
20	21°07.5'	158°25'	10/1/51	1714-1748	1521.2	17.6	18.2
21	20°47'	158°25'	10/1/51	2007-2040	1475.3	25.3	20.8
22	20 27'	158 25'	10/1/51	2253-2329	1424.1	24.9	17.7
23	20°07'	158°25'	10/2/51	0149-0222	1070.3	23.1	17.2
27	22°48'	158°25'	10/7/51	2343-0012	1032.9	26.7	18.9
28	22°28'	158°25'	10/8/51	0230-0306	1693.6	31.6	24.3
29	22°08'	158°25'	10/8/51	0525-0600	1556.5	22.5	21.8
30	21°48'	158°25'	10/8/51	0817-0850	1288.4	12.9	16.1
31	21°27.5'	158°25'	10/8/51	1107-1140	1574.8	17.1	24.0
32	21°07.5'	158°25'	10/8/51	1355-1427	1264.7	13.8	18.3
33	20 47'	158 25'	10/8/51	1640-1710	1329.0	15.7	17.2
34	20°27'	158°25'	10/8/51	1921-1954	1790.9	25.4	22.0
35	20°07'	158°25'	10/8/51	2225-2259	1891.4	35.3	25.6
38	22°48'	158°25'	10/15/51	0330-0402	1549.7	31.5	25.9
39	22°28'	158°25'	10/15/51	0612-0645	1544.9	17.9	18.4
40	22°08'	158°25'	10/15/51	0859-0931	1709.3	14.0	18.2
41	21°48'	158°25'	10/15/51	1144-1214	1318.6	13.9	19.6
42	21°27.5'	158°25'	10/15/51	1450-1522	1161.8	15.0	19.1
43	21°07.5'	158°25'	10/15/51	1737-1808	1373.8	16.5	16.5
44	20°47'	158°25'	10/15/51	2021-2049	1230.1	29.5	23.7
45	20°27'	158°25'	10/15/51	2308-2341	1509.5	24.8	17.7
46	20°07'	158°25'	10/16/51	0150-0222	1028.3	33.6	24.9

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[1] Local civil time corresponding to + 10 zone time.

Station	Sample	Position		Date	Time1/	Depth of haul meters	Water strained in m.³	Zooplankton cc./1000 m.³	
		North latitude	West longitude					Sample volume	Adjusted volume
1	1	22°08'	158°24'	11/13/51	2252-2322	200	1378.9	31.2	26.8
1	2	22°08'	158°23.5'	11/13/51	2340-0009	200	1130.9	29.3	25.0
1	3	22°08'	158°23'	11/14/51	0035-0108	200	1421.0	25.0	21.5
1	4	22°08'	158°22.5'	11/14/51	0128-0159	200	1411.1	23.2	20.1
2	1	22°09'	158°24'	11/14/51	1033-1110	200	1578.8	24.7	28.8
2	2	22°09'	158°25'	11/14/51	1127-1158	200	1179.7	29.1	34.1
2	3	22°09'	158°25'	11/14/51	1215-1244	200	1174.3	24.9	29.2
2	4	22°09'	158°26'	11/14/51	1305-1336	200	1132.1	26.6	30.9
3	1	22°48'	158°24'	11/14/51	2234-2311	200	1562.4	33.7	29.0
3	2	22°48'	158°23.5'	11/14/51	2330-0000	200	1242.5	34.2	29.2
3	3	22°48'	158°23'	11/15/51	0015-0045	200	1125.9	34.0	29.0
3	4	22°48'	158°22.5'	11/15/51	0101-0132	200	1252.4	28.3	24.4
4	1	22°48'	158°24'	11/15/51	1025-1055	200	1251.9	23.2	27.0
4	2	22°48.5'	158°24'	11/15/51	1117-1149	200	1182.0	22.9	26.9
4	3	22°49'	158°24'	11/15/51	1205-1236	200	1203.3	18.4	21.6
4	4	22°49.5'	158°24'	11/15/51	1250-1319	200	1109.6	22.9	26.7
5	1	22°08'	158°24'	11/15/51	1759-1827	200	1304.6	24.2	23.9
5	2	22°08'	158°26'	11/15/51	1843-1915	200	1168.8	30.4	29.2
5	3	22°08'	158°28'	11/15/51	1929-2000	300	1440.5	23.1	--
5	4	22°09'	158°30'	11/15/51	2032-2111	300	1449.0	27.8	--
5	5	22°09'	158°32'	11/15/51	2128-2224	500	1658.4	24.5	--
5	6	22°09'	158°34'	11/15/51	2243-2345	500	1981.0	15.7	--
5	7	22°10'	158°35'	11/16/51	0021-0046	200	1038.0	35.2	30.1
5	8	22°10'	158°37'	11/16/51	0102-0127	200	907.3	32.4	27.9
5	9	22°10'	158°39'	11/16/51	0138-0217	300	1368.3	21.9	--
5	10	22°11'	158°41'	11/16/51	0233-0310	300	1221.1	22.8	--
5	11	22°11'	158°42'	11/16/51	0324-0422	500	1975.3	19.4	--
5	12	22°11'	158°43'	11/16/51	0442-0546	500	2131.0	17.4	--
5	13	22°12'	158°44'	11/16/51	0615-0645	200	1168.8	23.8	24.2
5	14	22°12'	158°46'	11/16/51	0700-0728	200	1140.5	21.6	22.8

1/ Local civil time corresponding to + 10 zone time.

Table 22. (Cont'd)

Station	Sample	Position		Date	Time1/	Depth of haul meters	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
		North latitude	West longitude					Sample volume	Adjusted volume
5	15	22°12'	158°48'	11/16/51	0743-0819	300	1485.8	19.2	--
5	16	22°11'	158°49'	11/16/51	0839-0924	300	1859.3	13.6	--
5	17	22°11'	158°50'	11/16/51	0942-1040	500	2453.6	11.6	--
5	18	22°11'	158°51'	11/16/51	1058-1148	500	1825.4	12.1	--
5	19	22°10'	158°53'	11/16/51	1213-1238	200	1100.9	17.2	20.2
5	20	22°10'	158°54'	11/16/51	1249-1314	200	1098.6	20.1	23.4
5	21	22°10'	158°55'	11/16/51	1324-1405	300	1538.4	14.9	--
5	22	22°10'	158°56'	11/16/51	1419-1458	300	1601.2	12.6	--
5	23	22°10'	158°57'	11/16/51	1509-1614	500	2163.8	12.4	--
5	24	22°10'	158°58'	11/16/51	1646-1739	500	2006.5	10.0	--
7	1	21°29.5'	157°50'	11/18/51	1002-1039	5	1575.7	12.8	--
7	2	21°28.4'	157°49.8'	11/18/51	1044-1112	5	1147.8	19.9	--
8	1	21°30.8'	157°49.1'	11/18/51	0930-0950	5	1367.5	22.9	--
8	2	21°30.8'	157°49.1'	11/18/51	1149-1217	5	1360.7	30.9	--
9	1	21°31.2	157°48.9'	11/18/51	1250-1322	20	948.0	28.2	--
9	2	21°31.2'	157°48.6'	11/18/51	1333-1403	20	1376.8	31.1	--
10	1	21°31.9'	157°47.8'	11/18/51	1418-1448	125	1140.5	28.1	--
10	2	21°31.9'	157°47.8'	11/18/51	1457-1525	125	1106.5	24.6	--
11	1	21°33.2'	157°46'	11/18/51	1539-1606	200	1157.5	26.6	28.5
11	2	21°33.2'	157°46'	11/18/51	1616-1640	200	939.6	24.1	25.8
12	1	21°26.7'	158°12'	11/18/51	2249-2317	10	1225.4	24.8	--
12	2	21°26.7'	158°12'	11/18/51	2323-2351	10	1253.7	23.9	--
13	1	21°26.4'	158°12.5'	11/19/51	0002-0033	30	1615.1	32.1	--
13	2	21°26.4'	158°12.5'	11/19/51	0057-0129	30	1714.4	33.8	--
14	1	21°26'	158°13.6'	11/19/51	0145-0214	200	1237.5	34.7	30.2
14	2	21°26'	158°13.5'	11/19/51	0226-0256	200	1201.3	31.0	27.4
15	1	21°25.3'	158°14.5'	11/19/51	0308-0337	200	1166.0	30.2	27.3
15	2	21°25.3'	158°14.5'	11/19/51	0346-0418	200	1086.7	22.4	20.7
16	1	21°24.4'	158°16.3'	11/19/51	0434-0500	200	1044.3	30.8	29.2
16	2	21°24.4'	158°16.3'	11/19/51	0510-0537	200	999.0	28.6	27.8

1/ Local civil time corresponding to + 10 zone time.

ted from *Symposium on Marine and Fresh-water Plankton in the Indo-Pacific*, 1954

ATIONS IN ZOOPLANKTON ABUNDANCE IN THE CENTRAL EQUATORIAL PACIFIC, 1950-1952

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TIONS IN ZOOPLANKTON ABUNDANCE IN THE CENTRAL EQUATORIAL PACIFIC, 1950-1952

by

J. E. King*

lance of zooplankton as an index to production is significant to the study seas fishery resources of the tropical ical regions of the central Pacific being y the Pacific Oceanic Fishery Investi- I) of the U.S. Fish and Wildlife Ser- s report we shall review the primary zooplankton sampling in the equatorial our initial year, 1950, through 1952. l be examined for variations associated , longitude, and season. We shall ry briefly, certain relationships which st among the hydrographic features of ent, the zooplankton, and the tunas.

n is a basic food of much of the verte- f the sea. It is directly utilized even and fast moving fish as the tunas, the presently under study by these Investi- example, representatives of the follow- ve been captured in our plankton nets been found among the stomach con- ring and adult yellowfin tuna (Reintjes 53).

ids
ds
od larvae
l larvae

brachyuran larvae
heteropods
pteropods
cephalopods
tunicates
fish larvae and juveniles

the zooplankton, however, reaches the tly through intermediary forage orga- squid, fish, and the larger shrimp.

nkton sampling in this area has con- ally of scattered collections. Some of anographic expeditions, the *Challenger* and the *Dana*, while traversing the c, made a few hauls which were largely nd chiefly of value in systematic and distributional studies. The *Carnegie* visited the central Pacific in 1929 and made quantitative hauls on a generally north-south section crossing the Equator. The resulting data (Graham, 1941) are difficult to compare with our own but do provide evidence on variation in plankton dry weights as related to latitude and the equatorial current system. The work being carried out by POFI is, however, the first comprehensive quantitative survey of zooplankton abundance in the equatorial central Pacific and the first attempt to correlate the physical and chemical environment, zooplankton abundance, and tuna catch.

The Pacific Oceanic Fishery Investigations are under the directorship of Mr. O. E. Sette, who has contributed many of the ideas expressed in this report. Miss Joan Demond[1] and Mr. Thomas S. Hida[2] assisted in making the zooplankton volume determinations on which this report is based. We are indebted to Messrs. Garth I. Murphy[3] and Richard S. Shomura[3] for supplying the yellowfin tuna catch records. The hydrographic data were collected and processed under the supervision of Messrs. Thomas S. Austin[4] and Townsend Cromwell[5]. The author is responsible for combining and averaging the tuna catch records and the inorganic phosphate data for the purpose of comparing them with the zooplankton volumes.

This report is based on 405 collections taken on 10 cruises of the Fish and Wildlife Service vessel *Hugh M. Smith* during the years 1950 to 1952. The time of year of each cruise, the general area visited and the number of collections are listed in Table 1. The area sampled (Fig. 1) extends from 120° W. longitude on the east to 180° longitude on the west, with a range of latitude from 27° N. (on 175°W. longitude, to 14-1/2° S. (on 172°W. longitude). The geographic position for each plankton station and the value of each collection as a count

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or volume of zooplankton have appeared, or will appear, in other publications of the Fish and Wildlife Service (King and Demond, 1953; King and Hida, 1954). Most of the cruises consisted of one or more long series of stations (as illustrated in Fig. 2 for cruise 5) extending in a north-south direction, crossing the Equator and the major equatorial currents.

Cruises 2, 5, 8, 15 and 16 were combined hydrographic and plankton cruises and thus provide information on currents, temperatures, oxygen and inorganic phosphate for comparison with the zooplankton abundance. Cruises 7, 9 and 18 of the *Smith* were primarily tuna fishing expeditions on which some plankton collections were made; cruises 11 and 14 were combination fishing, hydrographic and plankton cruises.

The plankton nets used in making these collections were 1 meter in mouth diameter and about 5 meters in overall length. Front and middle sections of the net were of 30xxx silk grit gauze (apertures 0.65 mm square); the rear section and bag were of 56xxx grit gauze (apertures 0.31 mm square). The 30xxx grit gauze comprised about 97 per cent of the straining surface of the net.

Nets of this mesh size retained the tuna eggs (of about 0.80 mm diameter) and tuna larvae, the capture of which was one object of the study. Almost all phytoplankton passed through the net, and thus a relatively "clean" sample of zooplankton was obtained. A flow meter suspended in the mouth of the net gave an estimate of the amount of water strained on each haul. Thus the results could be expressed in terms of cubic centimeters of zooplankton per unit of water strained.

As we were limited to a single tow at each station, we chose to use, for the greater part, an oblique haul. This method of hauling has been shown by Winsor and Clarke (1940) to be subject to less sampling error and to provide more reliable and consistent results than vertical or horizontal hauls. In making the haul the net was lowered at a slow, uniform speed to a calculated depth of 200 meters (estimated from wire out and angle of stray from the vertical, assuming the towing wire to describe a straight line in the water), and then retrieved at the same slow, uniform speed. Following this practice the oblique tow to 200 metres required about 30 minutes, and approximately equal amounts of time were spent at all depths. The amount of water strained on each haul varied from 1,000 to 1,500 cubic metres.

For cruises 2, 5, 7 and 8, a measured fraction of each sample was counted and the displacement volume was determined (the zooplankton counts
are not utilized in this report). For all
cruises, the displacement volume of
sample was measured but no counts
During the course of the work, refineme
nique have been introduced which ten
more accurate estimate of the amou
plankton—as food—present at each s
tailed descriptions of the methods e
processing the samples are given in rec
(King and Demond, 1953; King and Hid

For purposes of comparison, the
volumes were grouped according to th
into 5-degree intervals of latitude and
intervals of longitude. The intervals
chosen were as follows: 0°00′ to 4°
to 9°59′, etc. The few samples occurri
were assigned to the 0°-4°N. group or t
group depending upon the direction t
was being traversed, e. g., if the directio
ment was to the south, the sample was
the southern (0°-4° S.) group. The
longitude selected were as follows: 120°
samples from 115°00′ to 124°59′, 130°
samples from 125°00′ to 134°59′, etc.

When the data from all 10 cruises were
irrespective of longitude and season int
latitudinal groups and graphically po
in figure 3B, the peak of abundance wa
occur near the Equator in the South
Current but displaced slightly to the
and spilling over somewhat into the Coun
The poorest areas within the range
sampled were those in the North Equatori
An average of zooplankton volumes,
figure 3B, obtained on four cruises in
waters during the years 1951 to 1953
Hawaii ranked a little higher than parts of
Equatorial Current, but considerably
the equatorial region.

Figure 3B is a composite, however,
many cruises occurring at different tim
year and with sampling along different
from 120° W. to 180°. A more accura
may be obtained from Table 2, where the
variation is shown for each 10 degrees of
Table 3 is included to point out differen
four major cruises, with two cruises (
occurring during the northern winter seas
cruises (5 and 11) occurring in the late
summer. Through an analysis of varia
and Demond (1953) found no significant
($P > 0.05$) between longitudes for both
and 8 but highly significant differences
between cruises. In general, it appear
equatorial region produced a larger zo
crop in the winter of 1950 than in the

summer crops of the two years are

vas constructed for the purpose of rther the variations with season of the th longitude. The sampled area in- ons of both hemispheres and since d no evidence as to natural seasons on abundance in the tropical Pacific, year was divided into quarters as Table 4. Since latitude is a third taken into account, Table 4 is arranged iations with longitude and "season" atitudinal groups: 4°N-0°, 0°-4°S. S. These are the latitudes for which most observations and they are also greatest plankton production. The s in the table indicate that longitudes ° produced in general the largest hough our data are not sufficiently provide entirely reliable conclusions. which summarizes the variation with r all observations between 9° 59′ N. . latitude, shows a gradient of increasing rom west to east, with a levelling-off Certain of the longitudes were sam- one period of the year, however, so of longitudinal variation may change ith future sampling.

t to seasonal variation, the period bruary—March ranked low for most July—August—September, almost eption, marked the period of greatest (great significance should probably buted to the three observations for November — December, 4°N.-0° ° W. longitude). Perhaps the most ure of the data as portrayed in Figure bsence of the great seasonal variation characteristic of plankton abundance titudes.

seas have been considered less pro- n those of higher latitudes on the t surface heating in the tropics results stratification of the sea, thus limiting ing by convection which would bring the euphotic zone (Delsman, 1939, 941; Sverdrup *et al.*, 1942, p. 942). al stratification does apparently exist much of the tropical and sub-tropical was learned, however, from the last *Carnegie* in 1929, that these generally itions are disrupted at the Equator by of the surface waters resulting in up- he latter was considered responsible ent of the surface waters and the production of much greater concentrations of plankton than were found in higher latitudes within the tropics and sub-tropics (Graham, 1941).

The existence of the divergence at or near the Equator, with resultant upwelling of nutrient-rich water, is substantiated by the researches of this laboratory. The nature of the upwelling and the causal forces involved are discussed by Cromwell (1951 and 1953) and Sette (MS). Apparently the strong east and southeast trade winds which prevail for the greater part of the year and the effect of the Coriolis force are the major influences governing this equatorial current system.

Basic nutrients, brought to the surface by the equatorial upwelling, are essential to the growth of phytoplankton; in the present studies the concentration of dissolved inorganic phosphate is used as an indicator of these nutrients. Figure 3A shows the variation in inorganic phosphate with latitude, as found on seven cruises in the central Pacific. We have no empirical explanation at the present time for the asymmetric distribution of phosphate with respect to the Equator. This may be related, however, to differences in the meridional components of the surface current in the region of the Equator, or perhaps to differences in the rate of utilization by phytoplankton. As indicative of the phosphate ⟶ phytoplankton ⟶ zooplankton eutrophic linkage, we have found a highly significant positive correlation between zooplankton and inorganic phosphate on the long north-south sections crossing the Equator (King and Demond, 1953).

The frequently appearing "fronts" (Cromwell, 1953) in the zone of convergence north of the Equator, at 2° to 4° N. latitude, may also contribute to the apparent greater abundance of life in the equatorial region. Floating organisms of high buoyancy may tend to congregate along the fronts just as driftwood does along a "current rip." Motile plankton forms capable of resisting the downward currents would also tend to concentrate in the surface waters; thus a rich pasturage for plankton-feeding animals could result.

The unusual abundance of marine life in the region of the Equator and the Countercurrent has been observed by many expeditions and world travellers while crossing the Pacific. The surface manifestations of the enrichment may have a counterpart in certain features of the bottom deposits of this area of the Pacific. Revelle (1944) points out the agreement between the southern boundary of the Countercurrent and the northern border of the Pacific *Globigerina* ooze area. Arrhenius

(1950) concluded from an examination of bottom samples collected by the Swedish Deep-Sea Expedition that in the Pacific the " biogenous component " increases strongly in the region between the Equator and the southern boundary of the Countercurrent "—where a biolith, rich in fossils of foraminifera, radiolaria and diatoms is thus deposited."

From October, 1950, to June, 1953, the Pacific Oceanic Fishery Investigations conducted experimental longline fishing for tuna on 10 cruises in waters of the equatorial Pacific. The fishing took place in essentially the same area with about the same boundaries of latitude and longitude as our plankton investigations. The longline method of fishing and the results obtained on these cruises have been reviewed by Murphy and Shomura (1953*a* and 1953*b*).

In the Pacific, several species of tuna are taken by the longline fishing method. In the equatorial central Pacific the yellowfin, *Neothunnus macropterus* (Temminck and Schlegel), constitutes by far the largest percentage of the catch. When the catches, in terms of yellowfin captured per hundred hooks fished at each station, are combined in 5-degree intervals of latitude, irrespective of longitude and time of sampling—as was done for the zooplankton to produce Figure 3B — the result (Fig. 3C) indicates the area of best catch to be at 4°N.—0° latitude. The average catch rate drops off very fast to the north and south of these latitudes.

It is rather obvious that there is more than a casual relationship between zooplankton and yellowfin tuna, but, as might be expected when using the average values of zooplankton and fish from a number of disconnected cruises, the latitudinal distribution of zooplankton and fish do not precisely correspond. There are several reasons why this might be so, but for the present discussion it is enough to establish that one of the basic food constituents of tuna — plankton — reaches a peak of abundance near the Equator in a region high in mineral nutrients and that this same region is also found to contain maximal concentrations of yellowfin tuna.

In summary it would seem that upwelling at the Equator, resulting from the equatorial divergence, replenishes the supply of nutrients in the surface waters and provides a suitable environment for the growth of phytoplankton. Since animal life depends on its food supply, conditions in this region are favourable for the development of a zooplankton population. Convergence in the surface water layers, occurring usually at 2° to 4° N. latitude, between the Equator and the southern boundary of the Countercurrent, tends to concentrate the zooplankton into a rich pasturage for forag
These in turn serve as food for the
such as the tunas. Thus, a product
the sea, starting from upwelled equat
results in the formation of a vast p
resource in the form of yellowfin tu

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Table 1

d, general area visited, and number of zooplankton samples collected on 10 cruises of the U.S. Fish and Service vessel *Hugh M. Smith* during the years 1950 to 1952.

Cruise period	Approximate longitude	Range of latitude	Number of samples
Jan.-Feb. 1950	170°W	23°N-4°S	12
Feb.-Mar. 1950	160°W	19°N-4°S	12
June 1950	180°	27°N	1
July 1950	170°W	25°N-5°S	26
July-Aug. 1950	160°W	20°N-4°S	24
Oct.-Nov. 1950	160°W	20°N-2°N	23
Nov. 1950	170°W	6°N	1
Jan. 1951	150°W	6°N	1
Jan.-Feb. 1951	160°W	20°N-7°S	41
Feb.-May 1951	170°W	20°N-14°S	45
June 1951	180°	25°N	1
June 1951	170°W	22°N-4°S	13
June 1951	160°W	20°N-1°S	11
Sept. 1951	150°W	19°N-4°S	45
Sept. 1951	160°W	2°N-1°N	5
Jan.-Feb. 1952	150°W	7°N-3°S	7
Jan.-Feb. 1952	160°W	1°N-6°S	9
Mar. 1952	170°W	6°N-5°S	13
Mar. 1952	180°	9°N-8°S	18
May-June 1952	140°W	9°N-7°S	60
Aug. 1952	150°W	2°N-3°S	14
Oct. 1952	120°W	7°N-8°S	13
Nov. 1952	130°W	9°N-4°S	10

Table 2

oplankton abundance as associated with latitude and longitude without regard to time of year of sampling. e means of zooplankton volumes (as cc per 1000m^3 of water strained). [Number of samples for each area ntheses.]

180°	170°*	160°*	150°*	140°*	130°*	120°*	Mean
12.5(2)	27.1(1)	..	..	..	..	..	17.4(3)
..	16.5(6)	24.6(4)	..	..	..	..	19.8(10)
..	21.6(8)	31.7(10)	16.4(3)	..	..	..	25.7(21)
..	14.7(13)	22.0(21)	20.1(8)	..	..	..	19.4(42)
19.6(5)	23.8(19)	30.6(31)	26.8(13)	51.2(18)	37.3(3)	41.8(2)	32.6(91)
27.2(5)	37.0(24)	37.0(34)	37.7(28)	34.8(17)	35.8(4)	38.2(6)	36.5(118)
25.9(4)	32.6(28)	36.8(20)	39.9(15)	38.9(19)	34.2(3)	37.9(3)	35.9(92)
15.4(4)	20.8(8)	28.7(5)	..	21.8(6)	..	29.6(2)	22.5(25)
..	16.5(3)	..	..	..	..	..	16.5(3)
24.1(14)	31.7(71)	34.6(85)	35.8(56)	41.7(54)	35.8(10)	38.8(11)	

* For latitudes 9°N to 4°S only.

Table 3.

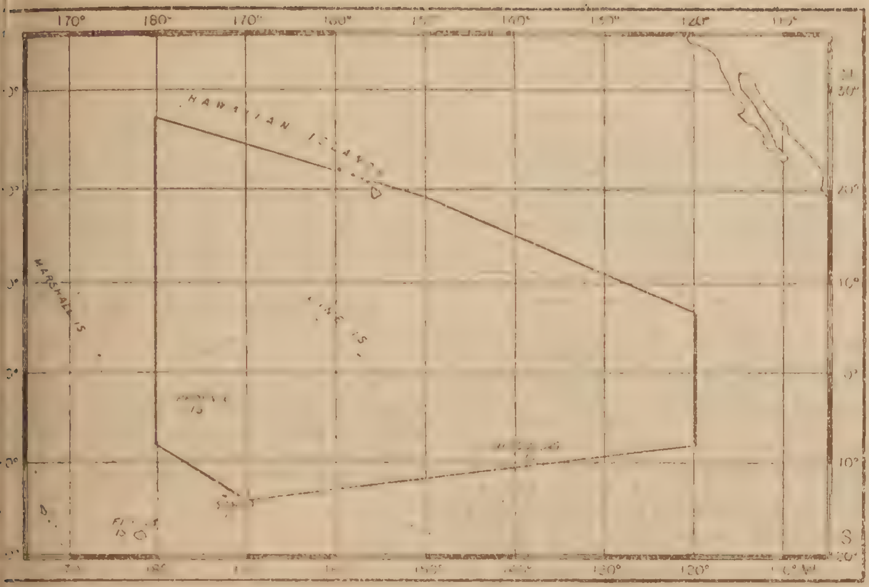
Variation in zooplankton abundance with latitude as obtained on four major cruises of the *Hugh M* given are mean zooplankton volumes (as cc per 1000m³ of water strained). [Number of samples for in parentheses].

Latitude	Cruise 2		Cruise 5		Cruise 8		
	Feb. 1950		July 1950		Feb.-Mar. 1951		
	170°	160°	170°	160°	170°	160°	150 Sectic
24°-20°N	10.8(2)	..	21.4(2)	28.9(1)	14.5(1)	15.4(1)	..
19°-15°	..	17.6(1)	25.9(3)	28.6(2)	14.2(3)	10.5(1)	..
14°-10°	11.2(3)	6.6(3)	20.4(4)	23.3(6)	12.5(5)	19.7(5)	17.0(
9°-5°	23.1(2)	26.4(3)	25.4(6)	43.2(5)	21.0(6)	23.4(12)	24.4(
4°-0°	53.2(2)	74.0(2)	42.0(4)	62.2(4)	35.4(12)	24.7(15)	41.6(
0°-4°	53.7(3)	57.7(3)	53.8(5)	36.5(6)	21.4(8)	36.8(4)	45.6(
5°-9°	..	..	31.5(1)	..	19.3(7)	34.1(3)	..
10°-14°S	..	..	..	..	16.5(3)	..	..

Table 4.

Variation in zooplankton abundance with longitude and time of year of sampling for certain latitudin are mean zooplankton volumes (as cc per 1000m³ of water strained). [Number of samples for each area an in parentheses].

	Jan.-Feb.-Mar.	Apr.-May-June	July-Aug.-Sept.	Oct.-Nov.-De
4°N-0°				
180°	27.2(5)	..	..	..
170° W	36.8(19)	20.1(1)	42.0(4)	..
160°	29.2(19)	27.7(3)	46.4(9)	68.0(3)
150°	25.0(3)	..	39.3(25)	..
140°	..	34.8(17)	..	..
130°	..	..	..	35.8(4)
120°	..	..	..	38.2(6)
Mean	31.8	33.1	41.2	44.3
0°-4°S				
180°	25.9(4)	..	..	..
170° W	27.5(17)	29.2(6)	53.8(5)	..
160°	38.5(12)	27.6(2)	36.5(6)	..
150°	26.3(1)	..	40.9(14)	..
140°	..	38.9(19)	..	..
130°	..	..	..	34.2(3)
120°	..	..	..	37.9(3)
Mean	31.2	35.9	42.4	36.1
9°N-4°S				
180°	24.1(14)	..	..	..
170° W	30.2(46)	27.8(9)	39.3(15)	..
160°	29.9(46)	28.7(7)	42.6(20)	19.2(1)
150°	25.4(8)	..	37.5(48)	42.8(12)
140°	..	41.7(54)	..	..
130°	..	..	..	35.8(10)
120°	..	..	..	38.8(11)
Mean	29.0	38.6	39.1	38.7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180°
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20°
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HAWAIIAN ISLANDS
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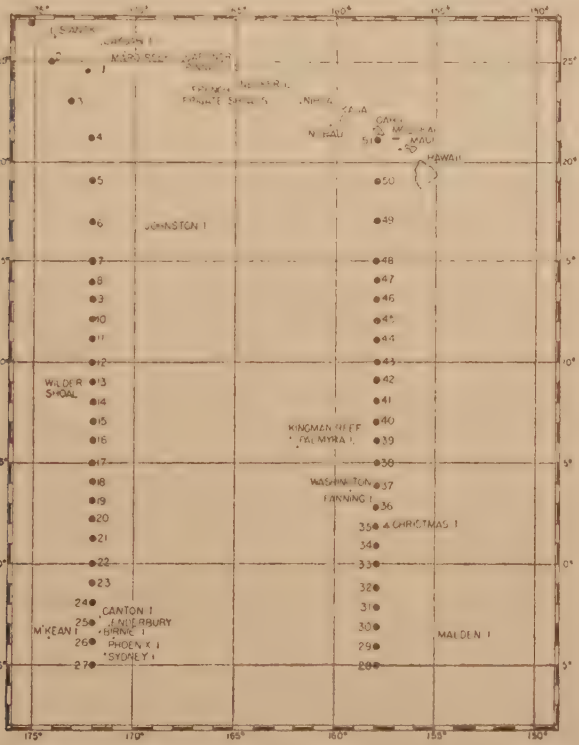
130°
120°

FIG. 1.—Map of the central Pacific showing the boundaries of the area covered in ese investigations.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10°
5°
0°
5°
MARO REEF
FRENCH FRIGATE SHOALS
NIHOA
NIIHAU
KAUAI
OAHU
MAUI
HAWAII
JOHNSTON I
WILDER SHOAL
KINGMAN REEF
PALMYRA I.
WASHINGTON I
FANNING I
CHRISTMAS I
CANTON I
ENDERBURY
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PHOENIX I
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FIG. 2.—Plankton station positions for cruise 5 of the *Hugh M. Smith*, showing the station pattern of one of the combined hydrographic and plankton cruises.

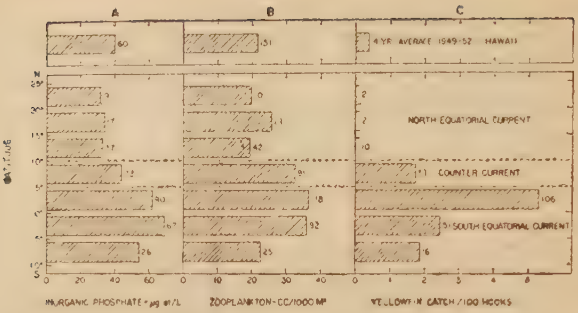

FIG. 3.—Variation with latitude of inorganic phosphate (A), zooplankton abundance (B), and yellowfin tuna catch (C), with the data combined into 5-degree intervals of latitude without regard to longitude and time of year. The approximate boundaries of the major equatorial currents are indicated. Part A is derived from cruises 2, 5, 8, 11, 14, 15 and 16 of the *Hugh M. Smith.* Part B is derived from cruises 2, 5, 7, 8, 9, 11, 14, 15, 16 and 18 of the *Hugh M. Smith* in the equatorial region and cruises 10, 12, 17 and 20 in Hawaiian waters. Part C is derived from cruises 7, 11 and 18 of the *Hugh M. Smith*; cruises 11, 12, 13, 14 and 15 of the *John R. Manning*; cruise 1 of the *Charles H. Gilbert* and cruise 1 of the *Cavalieri.* The vessels *Smith*, *Manning* and *Gilbert* are the property of the U.S. Fish and Wildlife Service. The vessel *Cavalieri* was chartered by the Government for this one fishing cruise. [The number of observations for each interval of latitude is indicated after each bar in the histogram.]

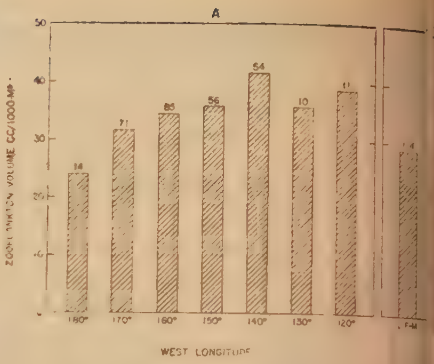

FIG. 4.—Variation in zooplankton at longitude (A) and season (B), for all observ 9° 59′ N. and 4° 59′ S. latitude. [The numl tions for each longitude and for each seas above each bar in the histogram].

VARIABILITY OF LONGLINE CATCHES OF YELLOWFIN TUNA

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

VARIABILITY OF LONGLINE CATCHES OF YELLOWFIN TUNA

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INTRODUCTION

A fundamental problem in inferring the density of a population from a sample or series of samples is the estimation of the magnitude and sources of variability inherent in the samples. Variability may arise from the way the population is distributed in space and from imperfections in the sampling method. The purpose of this paper is to provide a method of estimating the reliability with which longline[1] catches of yellowfin tuna[2] represent the relative abundance of the population.

As a prelude to estimating the variability of the longline catches we will first examine the way in which yellowfin are distributed in space. This will be followed by an empirical examination of the distribution of the catches in order to ascertain a transformation that will permit the application of conventional statistical methods. Finally, the variance will be estimated as a basis for establishing fiducial limits.

SOURCES OF DATA

The catch data used in this study of variability are from two sources: records of Japanese commercial fishing in the western equatorial Pacific in 1950 and 1951, and records of fishing conducted by U. S. Fish and Wildlife Service research vessels in the central Pacific in 1951 and 1952. The principal differences between the two types of data are: (1) The commercial vessels fished around 2,000 hooks along 50 miles of line while the research vessels fished only 240-480 hooks along 5-10 miles of line. (2) The commercial vessels, fishing in fleets, made many sets in particular areas while the research vessels, operating singly, made single sets of gear at stations spaced as much as 90 miles apart. (3) The records of the commercial fishery contain only total catch and total amount of gear for each set, whereas the records of the research operation include these data and other details including the catch of each hook along the line.

---

[1] The longline is used commercially to catch tunas and marlins in the Pacific Ocean by Japanese fishermen (Shapiro 1950) and by American fishermen in Hawaii (June 1950). It is also used by American fishery research organizations such as the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service to ascertain the abundance of deep swimming tunas and marlins in areas not supporting commercial fisheries.

[2] Neothunnus macropterus (Temminck and Schlegel)

DISTRIBUTION OF THE YELLOWFIN IN SPACE

The aspect of yellowfin distribution in space that bears on the problem of sampling variability is the presence or absence of aggregation or schooling, for this affects the variability and determines the type of statistical distribution that fits the catches. There is no direct evidence on the social habits of yellowfin when they swim at the depths fished by the longline (200 to 600 feet according to Murphy and Shomura 1953), but they are known to form relatively compact schools at the surface. Our first approach to the problem of schooling or non-schooling involves examination of the location of hooked fish along the line to ascertain whether the catch is randomly distributed or whether it is grouped. The second approach is to compare the relative variability between yellowfin and black marlin catches. This comparison depends on the probability that marlin are not schooled when they swim at subsurface levels because they are generally seen singly at the surface (Nakamura 1949).

Determination of schooling or non-schooling of yellowfin by analysis of the distribution of the catches along the line is analogous to a study of disease in plants that are growing in a row. If the diseased plants are scattered at random the interpretation would be that there is no evidence of contagion (Swed and Eisenhart 1943). Similarly, if the tuna catch is randomly distributed there is no evidence of schooling. An analysis of sequences (Mood 1950) is appropriate to ascertain whether the distribution of hooked yellowfin is random. This involved determining from the total number of hooks and the total catch of yellowfin the most probable number of runs of hooks alike with respect to their bearing or not bearing fish.[3] If the tuna are schooled, there should be more instances of two or more fish occupying adjacent hooks than if the tuna were randomly distributed in space, thus reducing the number of runs. A "t" test is used to estimate whether the actual number of runs is significantly different from the most probable number.

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[3] A run is defined as consisting of any number of consecutive hooks uniform with respect to occupancy or non-occupancy by fish and bounded at both extremes by changes in this respect. Thus the minimum possible number of runs in a longline set, which is one, would be achieved either by having a fish on every hook, or by having no catch at all. Conversely, the maximum possible number of runs would result from having a fish caught on every alternate hook. In this case the total number of runs would equal the number of hooks in the set, and each of the runs would comprise a single hook.

The distribution of hooked yellowfin along the line was studied for one cruise (Smith cruise 11)[4], selected because the mean catch rate was high and also nearly identical in all portions of the line, whereas during most cruises the portion of the line removed from the water last had a higher catch rate than those portions removed earlier. There were 28 fishing stations during Smith cruise 11, but only 15 of these could be used for the anlysis (table 1) because the technique required a minimum catch of 11 yellowfin. Nine of the 15 stations had fewer runs than expected, and 6 had more runs than expected. Of the 9 with fewer runs, 5 had significantly fewer, and in 3 of the 5 the numbers were highly significantly less than was to be expected from a random distribution. In contrast, none of the 6 positive deviations were significant. There is, then, considerable evidence that there were fewer runs than would be expected from a non-schooling population.

The tendency to school is probably greater than this evidence indicates, because the following four factors tended to obscure the manifestation of schooling: (1) About 15 percent of the hooks were occupied by fish other than yellowfin, and if a hook were occupied by some other species before a school of yellowfin chanced on the line, a potential single run might be split into three runs, thus increasing the number of runs by two. (2) There were 60 fathoms between adjacent hooks of two consecutive baskets, whereas hooks within a

---

[4] The line used on this cruise was made up of 40 baskets or "skates" of gear essentially as described by Niska (1953), and fished in a manner described by Murphy and Shomura (1953). Briefly, each set consisted of a connected series of 40 main lines supported in the water by a buoy at each connection. Attached to each main line were six evenly spaced hooks. In effect the set of gear in the water resembled a series of 40 catenaries, and since the hook lines were equal in length, the hooks within each basket were fishing at different levels.

Table 1. Analysis of the number of runs of yellowfin tuna on 240-hook (40-basket) sets of longline gear (Smith cruise 11)

Station	Number of tuna (n_1)	Number of hooks without tuna (n_2)	Total number of hooks [1] ($n = (n_1 + n_2)$)	Actual number of runs (d)	Most probable number of runs ($2n\alpha\beta$)	$t = \frac{d - 2n\alpha\beta}{2\alpha\beta\sqrt{n}}$
1	23	217	240	29	41.59	-4.690**
2	12	226	238	25	22.79	+1.496
3	38	201	239	63	63.92	-0.222
4	25	215	240	37	44.79	-2.695**
5	19	221	240	35	34.99	+0.004
6	37	201	238	65	62.50	+0.618
7	17	220	237	33	31.56	+0.702
8	42	191	233	65	68.86	-0.855
9	25	200	225	27	44.44	-5.889**
10	11	228	239	19	20.99	-1.463
11	20	218	238	35	36.64	-0.690
12	30	206	236	45	52.37	-2.163*
13	15	221	236	29	28.09	+0.496
14	71	167	238	104	99.64	+0.675
15	31	203	234	47	53.79	-1.930*
Pooled	416	3135	3551	658	706.95	-4.127

[1] Data on variations in the numbers of the original 240 hooks were unobtainable. In the analysis they were treated as nonexistent.

* Significant at .05 level.
** Significant at .01 level.

sket were separated by only 30 fathoms. (3) The hooks were not l fishing at the same depth and this decreases the chance of a hool's leaving more than one of its members on the line unless ere is a considerable vertical component to the shape of a school.) Whenever a tuna or other fish takes a bait without becoming hooked potential sequence of yellowfin is broken. It seems almost certain at had these four factors been absent the number of runs would have viated even more from the expected number. This lends qualitative upport to the conclusion that the subsurface yellowfin are aggregated ather than randomly distributed in space.

Providing an additional test of schooling or aggregation of ellowfin is a comparison of the variability of black marlin and ellowfin tuna catches made on the same gear at the same time and lace. The basis for this comparison is the assumption that the de- ree of variability of the catch of any species increases with the degree f aggregation of that species. Black marlin are not a schooling species hile at the surface, whereas yellowfin are usually aggregated into com- act schools. If these contrasting behaviours are retained when the sh occupy deeper levels, there should be a difference in the relative ariability of the catches.

A comparison of the variability of black marlin and yellowfin atches is given in figure 1, where each point is based on a catch from ne approximately 2,000 hooks comprised in one set of longline gear. t is at once apparent that the yellowfin catches are much more variable han those of the marlin, though the catch rates per 100 hooks are nearly qual.

Numerical expression of this difference in variability has been btained by testing the frequency distribution of the catches against a Poisson distribution appropriate to the mean catch rates, following the nethod of Snedecor (1948). The test of the yellowfin catches for the eriod October 2-10 (selected for relative homogeneity in catch rate), vith a catch rate of .454 fish, yielded a chi-square of 47 with a P of ess than .000001. On the other hand a similar test of the marlin catches or the period October 2-12, with an average rate of .656, yielded a hi-square of only 11, P of .03. Thus the marlin catches differ only lightly, though significantly, from the Poisson distribution, whereas the ellowfin catches do not even approach conformance with the Poisson, ndicating that some factor is introducing great variability.

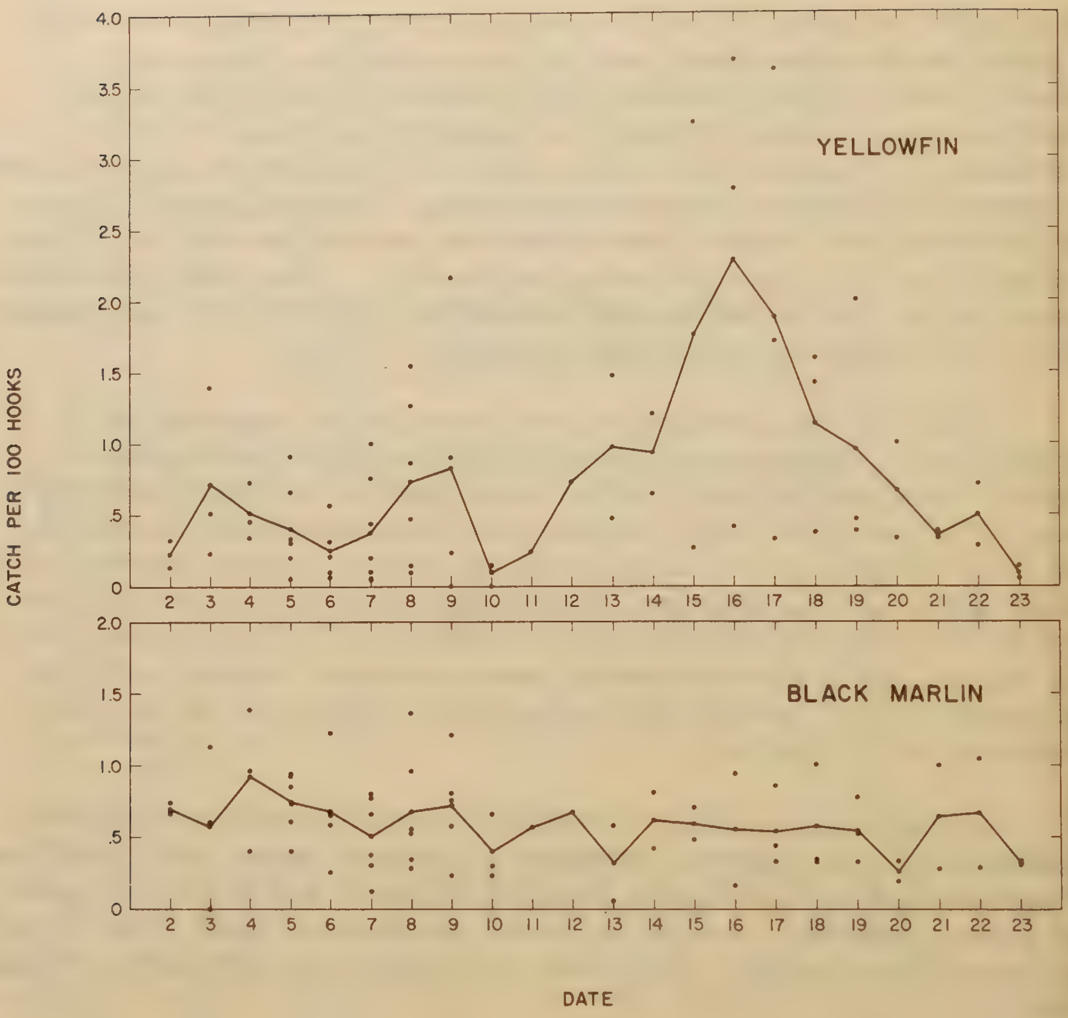

FIG. 1. CATCHES OF BLACK MARLIN AND YELLOWFIN TUNA FROM 6° N. LATITUDE, 178° E. LONGITUDE DURING OCTOBER 1951. THE CATCH RATES PLOTTED AGAINST THE CORRESPONDING DAY OF THE MONTH ARE BASED ON LONGLINE SETS OF APPROXIMATELY 2,000 HOOKS.

In conclusion, there is considerable evidence that yellowfin tuna are not randomly distributed in space but rather are aggregated. This is indicated by the distribution of hooked yellowfin along a longline, and by the great variability of longline yellowfin catches when contrasted with longline black marlin catches. This apparent tendency to aggregate must be taken into consideration when approaching a statistical treatment of yellowfin tuna catches made by the longline.

TRANSFORMATION OF THE CATCHES FOR ROUTINE STATISTICAL TESTS

In order to apply routine statistical procedures, such as analysis of variance, to enumeration data of the type obtained by longline fishing for yellowfin tuna, several conditions must be met (Barnes 1952). The most important of these are normality of the distribution and independence of the mean and standard deviation. These conditions obtain if the event under study (catching a yellowfin) has a high enough probability of occurrence and a random distribution. The catch rates of yellowfin tuna are of a magnitude to suggest a Poisson distribution, but the presence of schooling or aggregation, previously demonstrated, results in too many extremely low or extremely high values to fit a Poisson distribution (Quenouille 1949, Barnes and Marshall 1951). Under these circumstances a distribution such as the negative binomial more nearly fits the data, and the catches must be transformed prior to the application of statistical tests.

The need for transformation of longline yellowfin catches is indicated graphically in figure 2. These catches show a linear relation between the mean and the standard deviation. In order to overcome this difficulty two seemingly appropriate transformations were tested on these data. The first transformation was based on the assumption that the catch rates fit a negative binomial in which the distribution of schools follows a Poisson form and that of the catches from schools a logarithmic form (Quenouille 1949). Our procedure follows the methods described by Anscombe (1949). This requires estimating a value of k common to the eight distributions by fitting successive values of k into the formula:

$$T = \frac{(N - 1)s^2 - (N - 1 - 1/k)\,\bar{r}(1 + \bar{r}\ 1/k)}{(\bar{r} + k)^2}$$

(N = number of items; s^2 = sample variance; $\bar{r}$ = average catch per set). This trial and error process is continued until the sum of T for each of the eight distributions equals or nearly equals zero. For our data a value of 2.24 was selected for k. The data were then transformed[5] by

$$y = \sinh^{-1}\sqrt{\frac{r + c}{k - 2c}}$$

since we wished the transformation to be applicable to sets of data with low catch rates. For comparison, the much simpler logarithmic transformation commonly used when the standard deviation is proportional to the mean $[y = \log (r + 1)]$ was also applied to the same sets of data.

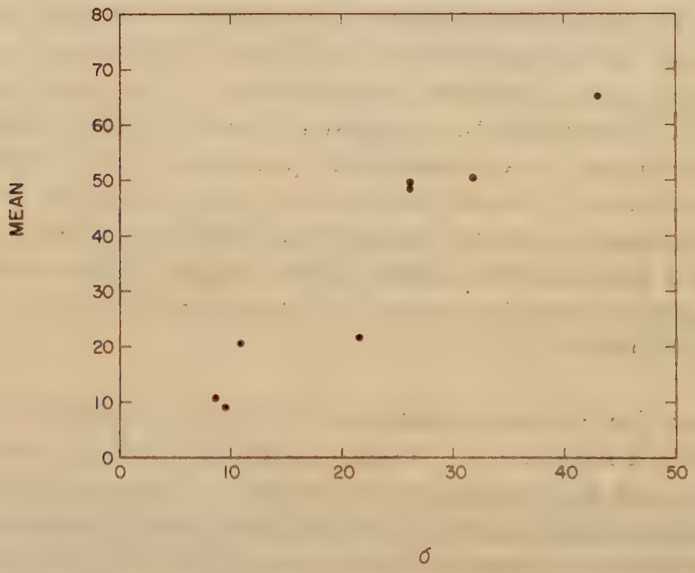

FIG. 2. RELATION BETWEEN MEAN AND σ FOR EIGHT SETS OF UNTRANSFORMED LONGLINE CATCHES. EACH POINT REPRESENTS THE MEAN AND σ FOR A SERIES OF 2,000 HOOK SETS AT ONE LOCALITY IN ONE MONTH.

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[5] This follows Anscombe 1949, formula 7. C is given the value of 0.2 conforming with our low value of k; r is the individual catch.

Statistics on the raw data and on the two transformed distributions are given in table 2, and the relations of the means and standard deviations of the two sets of transformed catches are shown graphically in figure 3. It is at once apparent that both transformations have significantly reduced the correlation between the standard deviation and the mean. (For instance, the logarithmic transformation has reduced the correlation coefficient of the mean and standard deviation to -.37, which is not significant.) The normalizing effect of the transformations is indicated in figure 4, in which the raw data distributions are plotted with the distributions of the transformed catches. Both sets of transformed data indicate a tendency to depart from normality, but this does not appear to be serious. Inasmuch as there is little to choose between the two transformations, we will use the less tedious logarithmic transformation in estimating the variance of longline catches of yellowfin tuna.

VARIATION OF THE YELLOWFIN CATCH OF A SINGLE SET OF LONGLINE GEAR

Having selected a logarithmic transformation as the most practical way to overcome the effect of schooling of yellowfin on the variability of longline catches of that species, we now consider the problem of estimating the variance of catches made by the longline gear used by POFI. Estimation of the variance of the results of any sampling technique is best effected by consideration of replicate samples. These were not available, and as a substitute individual sets of gear were subdivided into 2 or 4 subsets, each subset consisting either of the sum of the catches of alternate baskets or of every fourth basket. This scheme was adopted in order to avoid bias due to the longer time that one end of a series of baskets was fished.[6]

The variance of a single subset was estimated by applying a standard analysis of variance (Snedecor 1948) to the logarithmically

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[6] The subdivision of sets into subsets by combining alternate baskets raises the question of disturbing the relation between σ and the mean by breaking up runs of fish that might include the ends of two adjacent baskets. This does not appear serious as the double distance between the end hooks of adjacent baskets, as pointed out, considerably reduces the probability of disturbing a run, i.e., the runs are already broken up in the field before the application of the analysis.

Table 2. Comparison of three treatments of the eight sets of longline yellowfin catches shown in figure 2.

Set No.	N	Raw data			Logarithmic transformation (N+1)			Hyperbolic transformation		
		Mean	σ^2	σ	Mean	σ^2	σ	Mean	σ^2	σ
1	45	50.23	911.26	31.87	1.600	.1012	.3181	2.260	.1344	.3666
2	40	9.23	90.98	9.54	0.839	.1107	.3337	1.347	.2172	.4661
3	28	21.67	461.82	21.49	1.224	.1672	.4089	1.748	.2159	.4646
4	45	10.77	77.98	8.83	0.937	.1010	.3178	1.492	.1502	.3876
5	25	20.88	118.62	10.89	1.295	.0402	.2005	1.882	.0525	.2290
6	27	49.37	683.95	26.15	1.482	.0570	.2387	2.312	.0791	.2813
7	98	48.25	682.79	26.13	1.626	.0596	.2443	2.272	.0512	.2262
8	102	65.21	1856.94	43.092	1.729	.0856	.2925	2.379	.1144	.3382

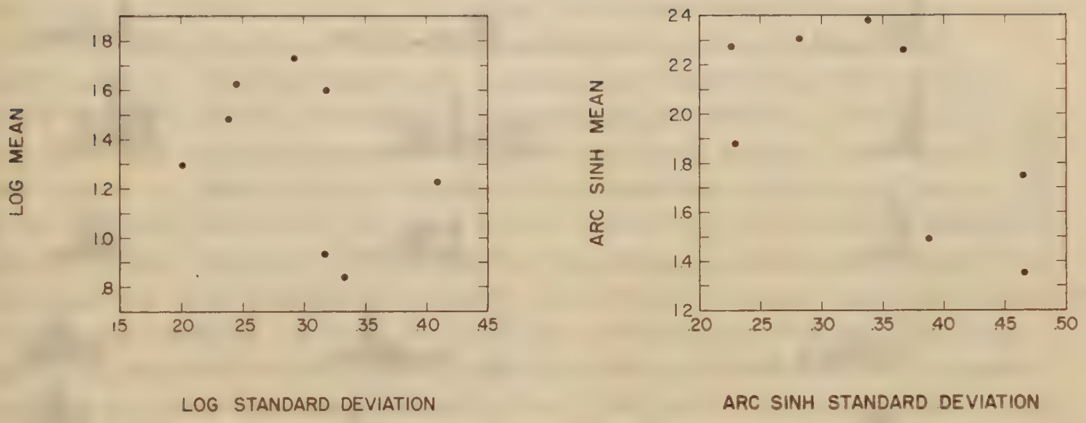

FIG. 3. RELATION OF MEAN AND STANDARD DEVIATION OF TRANSFORMED YELLOWFIN CATCHES.

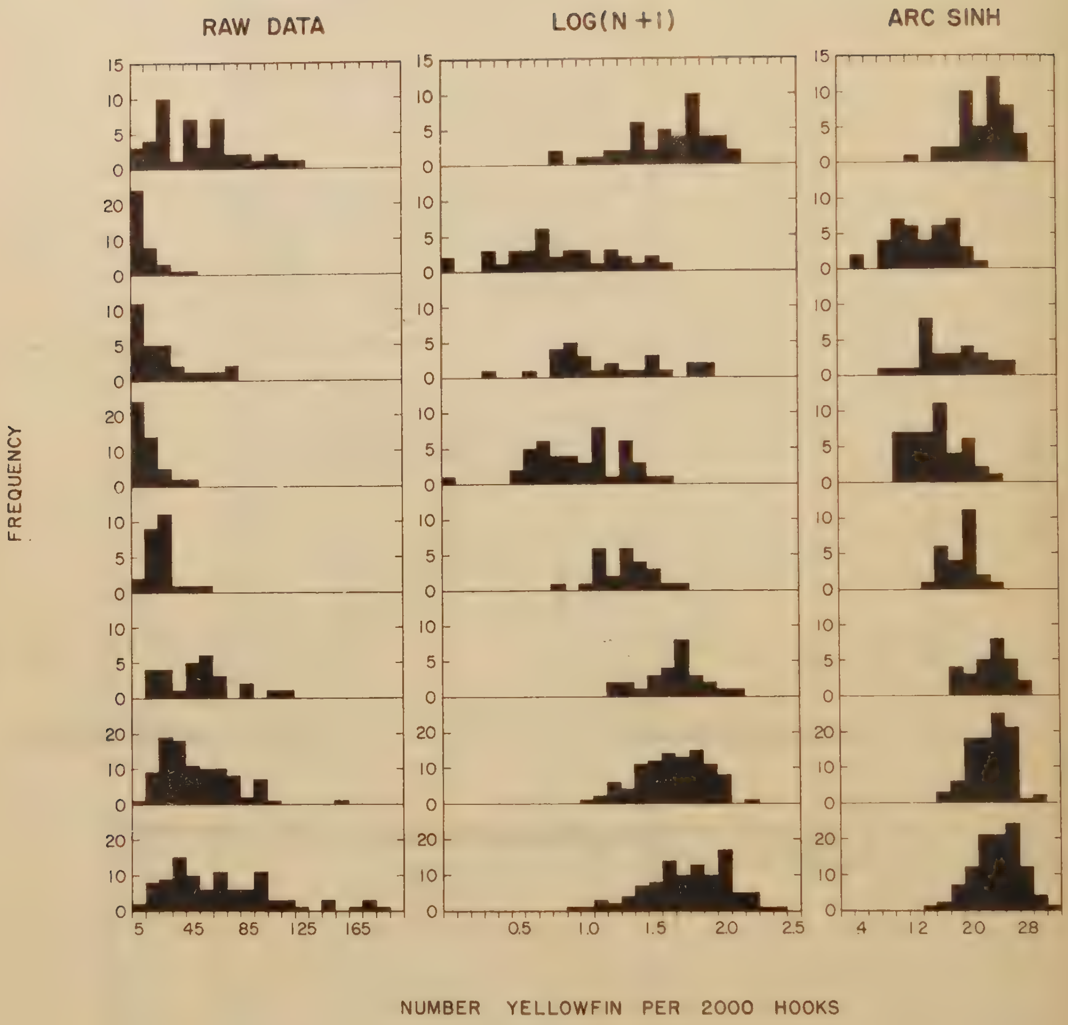

FIG. 4. ORIGINAL YELLOWFIN TUNA CATCHES, LOGARITHMICALLY TRANSFORMED CATCHES, AND CATCHES TRANSFORMED BY THE ARC SINH FORMULA. THE DATA CORRESPOND TO THOSE USED IN TABLE 2.

transformed paired catches, and then interpreting the "discrepance" as an estimate of the variance of a single subset. The only deviation from the usual computational technique was the rejection of sets of paired data of which one member was a zero. This was done because the effect of this alteration was less serious than the effects of the more commonly used adjustments for zero values. It resulted in rejection of as much as one-sixth of the data from one set, probably reduced the variance slightly, and of course limits the analysis to catch rates of more than one fish per 100 hooks.

The first series of fishing stations subjected to analysis of variance furnished estimates for 18-, 37-, and 74-basket sets of longline gear. The actual amount of gear fished during these stations varied from 60 to 84 baskets, 80 being the most typical number. Replicate fishing stations were obtained as follows: First, each station's set was divided into four subsets by combining the catches of every fourth basket, yielding 104 subsamples from 26 stations. (Equal numbers of baskets were obtained in each subset by discarding the last one, two or three baskets of a station when necessary). The 104 subsamples were formed into a series of 52 paired subsamples by pairing those derived from adjacent baskets, and two pairs were rejected because they contained a zero value. The mean number of baskets in this series was 18. Next, each of the 26 stations was divided into paired subsamples by pooling the catches of alternate baskets, again discarding superfluous baskets at the end of the set of gear. The mean number of baskets in this series was 37. Finally, each station was regarded as a unit, and stations occurring on consecutive days were paired yielding 14 pairs with a mean of 74 baskets.[7]

Analyses of variance[8] of these sets of catch records (table 3) indicate a substantial reduction in the estimated σ with increasing numbers of sampling units (baskets). This reduction is almost exactly proportional to the reduction to be expected from the theoretical relationship between σ and the number of sampling units (fig. 5).

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[7] During the collection of these data the geographical distance between any two consecutive stations was slight, and certainly did not involve movement to another zone of the ocean. There is, then, a priori reason to regard the catch on a succeeding day as a replicate. Two additional stations were used in this series which could not be used previously because only the total catch was recorded.

[8] In the computation the logarithms of the catches shown in table 8 (see appendix) were utilized. Since unequal amounts of effort are involved in some pairs in the 74-basket series, a simple ratio adjustment was applied to all members so as to equate the catches to those to be expected had there been 80 baskets in each pair. The use of the less tedious 80 basket adjustment is mathematically justified because of the use of the logarithms of the variates.

The near identity of the empirical reduction in σ with the reduction calculated from the σ of the 18-basket subsets indicate that no substantial new sources of variation were introduced when 2 consecutive days of fishing in the same area were considered as replicates. Perhaps the close approximation also serves as a measure of the suitability of the logarithmic transformation for this type of longline catch.

In addition to the estimate of σ for an 18-basket subset that can be derived from the previous analysis, values were calculated from three other series of 20-basket subsets. These latter were from 40-basket stations fished as much as 90 miles apart, and were obtained by pooling the catches of alternate baskets. The analysis of these data is shown in table 4. Considering the 20-basket value derived from table 3 with the three values from table 4, the range of the logarithmic σ of a 20-basket set (.191-.248) appears to represent sampling variation. It follows that the best estimate of the σ of a 20-basket set of longline gear is obtained by averaging the four empirically obtained variances and extracting the square root of the mean variance, yielding a mean value of .229.

It does not follow that the estimate of σ obtained from our carefully controlled experimental fishing can be applied to other types of longline fishing, such as Japanese commercial fishing, in which such variables as the length of time the gear is in the water vary considerably from day to day. As a test, two trial calculations were made on series of data derived from Japanese commercial fishing in which the sampling unit was about 2,000 hooks fished per day instead of the 240-400 hooks fished by POFI. The first series was obtained by pairing consecutive days' fishing by one vessel. The second series was obtained by selecting a block of ocean 60 miles square and pairing catches that occurred in that block on the same date without regard to vessel identity. As may be seen from table 5, these two methods furnished nearly identical estimates of σ, but they are larger than that obtained from our own fishing.

Considering hook or basket number only, extrapolation of the estimated σ of our experimental fishing (.229 for a 20-basket set) to

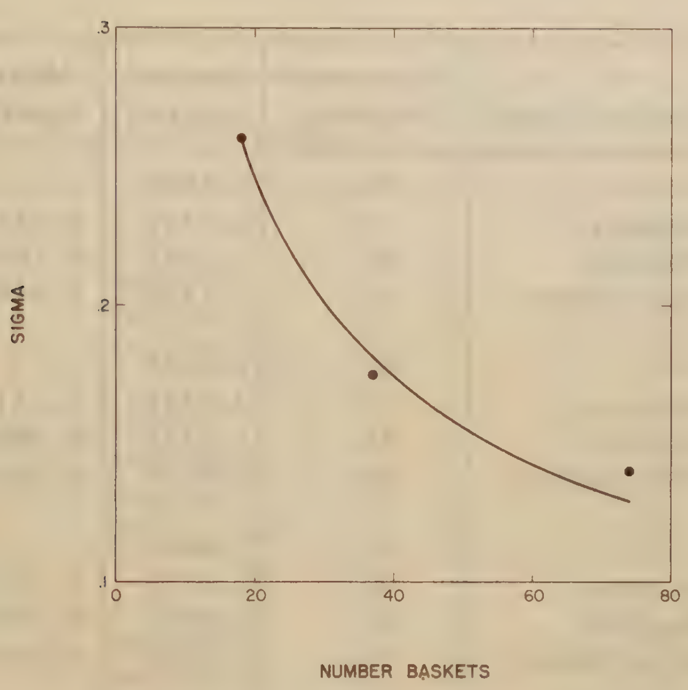

FIG. 5. σ (EQUAL TO SQUARE ROOT OF DISCREPANCE MEAN SQUARE) PLOTTED AGAINST NUMBER OF BASKETS IN THE SAMPLING UNIT. CURVE CALCULATED FROM THE σ OF THE 18-BASKET SUBSETS.

Table 3. Analyses of variance of yellowfin catches of paired 18-, 37-, and 74-basket sets (6 hooks to a basket). The values used are the logarithms of the catches in table 8 (appendix).

Number of baskets	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
18	Total	99	8.5969		
	Subsets	1	0.0219	0.0219	
	Stations	49	5.2342	0.1068	
	Discrepance	49	3.3408	0.0682	0.261
37	Total	51	3.2085		
	Subsets	1	0.0212	0.0212	
	Stations	25	2.4188	0.0968	
	Discrepance	25	0.7685	0.0307	0.175
74	Total	27	1.2881		
	Subsets	1	0.0212	0.0212	
	Stations	13	1.0087	0.0776	
	Discrepance	13	0.2582	0.0199	0.141

Table 4. Analyses of variance of yellowfin catches for three sets of 40-basket stations. Each set was subdivided into two duplicate sets for analysis. The values used are the logarithms of the catches in table 9 (appendix).

Set number	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
1	Total	51	5.6903		
	Subsets	1	0.1562	0.1562	
	Stations	25	4.0752	0.1630	
	Discrepance	25	1.4589	0.0584	.242
2	Total	39	6.5611		
	Subsets	1	0,0138	0.0138	
	Stations	19	5.8517	0.3080	
	Discrepance	19	0.6956	0.0366	.191
3	Total	35	3.3816		
	Subsets	1	0.0200	0.0200	
	Stations	17	2.4518	0.1442	
	Discrepance	17	0,9098	0.0535	.231

Table 5. Analyses of variance of series of Japanese commercial fishing longline yellowfin catches (about 2,000 hooks or 350 baskets per set). The values used are the logarithms of the catches in table 10 (appendix).

Set number	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
1[1]	Total	43	4.6779		
	Samples	1	0.0539	0.0539	
	Stations	21	3.6408	0.734	
	Discrepance	21	0.9832	0.0468	0.21
2[2]	Total	77	6.1943		
	Samples	1	0.0005	0.0005	
	Stations	38	4.5656	0.1201	
	Discrepance	38	1.6282	0.0429	0.20

[1] This series is based on all the fishing in a block bounded by 1°-2° N. latitude and 160°-161° E. longitude during May 1951. A pair was formed from two consecutive sets as they appeared in a tabulation by days. The maximum time interval between the members of any pair is therefore 1 day.

[2] This series is based on the fishing of two catcher vessels. A pair consists of two consecutive days' fishing by one vessel. If there was a break in time of more than 1 day or in distance of more than 1 degree, the pair was rejected.

the 350 baskets yield a value of .055, considerably smaller than the value of .212 obtained by averaging the two values for commercial fishing. Very likely this difference was largely caused by failure to rigidly control the conduct of each fishing operation in the instance of the commercial fishing, thus increasing the variability of the catches. This probably arose in part because commercial operators would have no particular reason to fish in an identical manner each day, and furthermore precise control would probably be more difficult when fishing 350 units of gear than with 40-80 units of gear. Differences in gear design and differences in the spatial distribution of the fish between the central Pacific, where the POFI fishing was carried out, and the western Pacific, where the commercial fishing was done, may also have introduced additional variability.

The demonstration that the same estimate of variability cannot be applied to situations as widely different as small experimental sets of fishing gear and large commercial sets indicates that our results will not be valid elsewhere unless the general conduct of the fishing is reasonably identical. The general method of determining the variability does, however, appear to have wide application, even though the specific numerical results obtained apply only to the fishing carried out by POFI.

SETTING FIDUCIAL LIMITS ON THE CATCHES

The average σ (.229) of the 20-basket POFI longline sets derived in the previous section appears to represent the best basis for setting fiducial limits on the catches of this type of gear when it is used in the same manner. From this estimated σ fiducial limits can be estimated for any station based on 20 to 80 baskets of gear.

If it is desired to set 95-percent confidence limits on a catch based on 20 baskets of gear, the 2 σ limits ($\pm$.458) are converted to ratios by using the antilogs, giving fiducial limits of 35 percent (100 x 1/2.87) to 287 percent (100 x 2.87). Applied to a catch of 10 fish per 100 hooks, the 95-percent confidence limits would be 3.5 to 28.7 fish per 100 hooks. To estimate the fiducial limits of a set of a number of baskets different from 20 it is only necessary to follow the above procedure after adjusting the value of 2 σ by the formula where N is the

$$\frac{.458}{\sqrt{N/20}}$$

number of baskets in the set. This has been done for numbers of baskets between 20 and 80 as shown in table 6.

In order to compute the 95-percent limits of the average of several fishing stations it must be assumed that the stations share a common variance. This assumption appears to be met within the central Pacific area, but might not apply between the central Pacific and other areas, where such factors as the schooling habits of the fish might differ. Following this assumption, it is only necessary to sum the number of baskets involved and calculated a new 2 σ based on the relationship of the number of baskets involved to the number used in calculating the basic σ (.458 for 20 baskets).[9]

Table 6. Two sigma (95-percent) limits for catches of yellowfin tuna made on the gear used by Pacific Oceanic Fisheries Investigations.

Number of baskets	Lower limit in percent	Upper limit in percent
20	35	287
30	42	237
40	47	211
50	51	195
60	55	183
70	57	176
80	59	170

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[9] Actually, this procedure is valid only for geometric means, but it is a useful approximation if the catches do not range through orders of magnitude. If these conditions are not met, the method developed by Sette and Ahlstrom (1948) for setting fiducial limits on logarithmically transformed data appears more appropriate.

For convenience in estimating the limits of catches of several stations or single stations (up to 80 baskets in size of set) figure 6 has been prepared, following the procedures outlined in this section. Although it is primarily designed to furnish a guide to the 95-percent limits of catches made by POFI vessels, it can serve as a rough estimate of these limits for other similar exploratory longline investigations, provided the construction and method of handling the gear are not too dissimilar.

SUMMARY

A study of the variability of longline catches of yellowfin tuna was conducted (1) to establish a means of estimating the variance of catches made with different amounts of gear in a single set or station, and (2) to suggest a method of estimating the variance of a catch rate derived from the average catches of several stations. Pursuant to this, the existence of schooling was investigated, and the suitability of two transformations was tested empirically.

The evidence for schooling of subsurface yellowfin is from two sources: (1) An analysis of runs indicating that they are clumped or grouped on the line; and (2) the markedly greater day-to-day variation in yellowfin catches as compared with the catches of a non-schooling fish, the black marlin.

The skewness of the data and the linear relation of the mean and σ occurring in the catch data make it desirable that they be transformed before applying statistical analysis. A logarithmic transformation appears to be the most appropriate.

The variances of 18-, 37-, and 74-basket sets were investigated by analysis of variance on the logarithmically transformed catches. The square root of the discrepance, interpreted as σ, was found to be inversely proportional to the square root of the number of baskets in the sampling unit, when the construction of gear and method of operation were held constant. Analysis of two groups of Japanese commercial fishing catches, based on 350-basket sets, gave estimates of σ considerably larger than would be expected if the σ calculated from the smaller sets were adjusted to the 350-basket level. This suggests that there was a lack of standardization in the conduct of the commercial fishing.

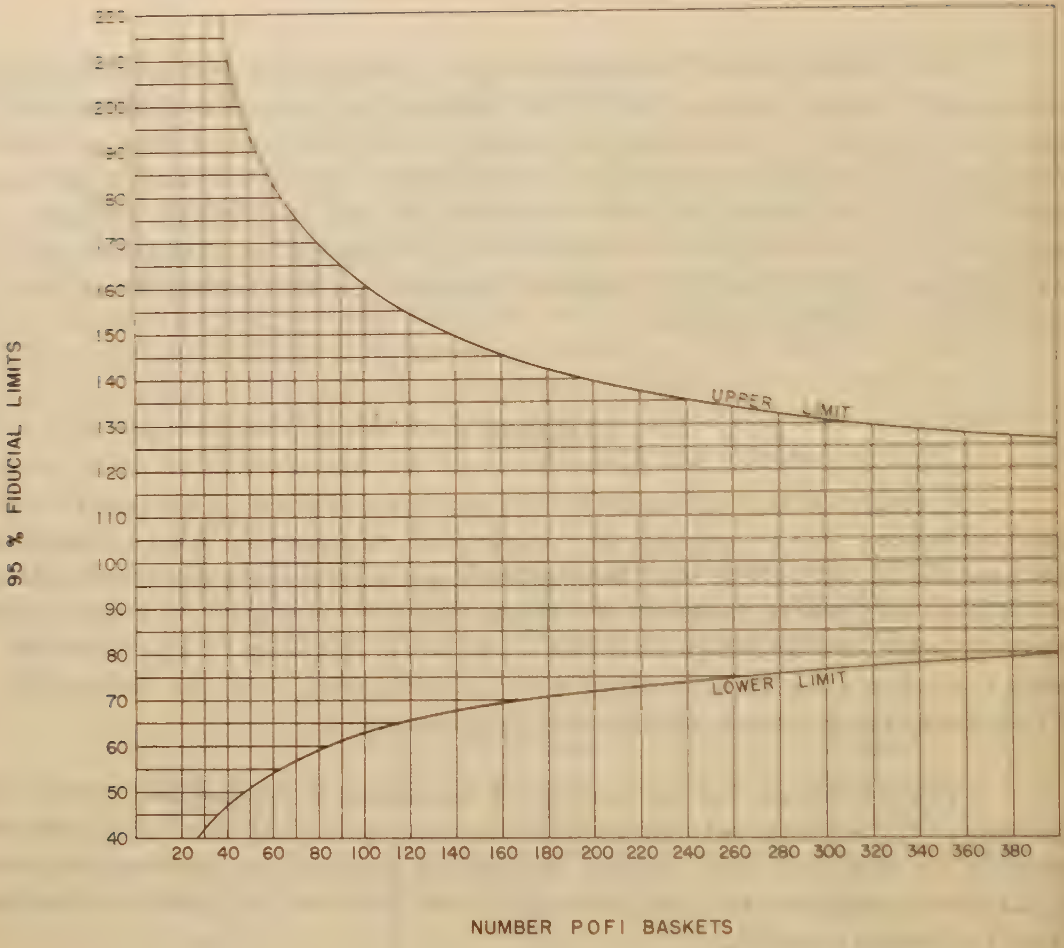

FIG. 6. NINETY-FIVE-PERCENT FIDUCIAL LIMITS FOR CATCHES OF YELLOWFIN TUNA MADE WITH THE TYPE OF LONGLINE GEAR DESCRIBED BY NISKA (1953). THIS GRAPH MAY BE USED TO ESTIMATE THE 95-PERCENT (2 σ) LIMITS FOR THE CATCH OF ANY STATION OF 20-80 BASKETS OR ANY COMBINATION OF SUCH STATIONS. FOR A COMBINATION OF STATIONS THE APPROPRIATE LIMITS ARE READ BY ENTERING AT THE TOTAL NUMBER OF BASKETS INVOLVED, AS IN THE INSTANCE OF A SINGLE STATION. FOR INSTANCE A CATCH OF 10 YELLOWFIN/100 HOOKS BASED ON 120 BASKETS (e.g. 3, 40 BASKET STATIONS) HAS LIMITS OF 6.5/100 15.5/100 HOOKS.

The quadratic mean σ of four sets of transformed data is used as the best estimate to apply to longline catches made by POFI. By appropriate application this σ can be used to estimate confidence limits for the yellowfin catches of single stations, or groups of stations, provided certain limitations are taken into account.

APPENDIX

Table 7. Eight sets of Japanese commercial yellowfin catches (catch per 2,000 hooks) on which table 2 is based. Each figure represents one day's fishing. The catches were made in the western equatorial Pacific in 1951.

May 1°N. L., 160°E. L.	October 2-10 6°N. L., 178°E. L.	October 11-23 6°N. L., 178°E. L.	October 6°N. L., 177°E. L.	August 6°N. L. 173°E. L.
12.00	6.48	7.78	4.32	54.38
20.40	0.00	55.55	2.67	12.58
5.96	30.84	8.42	9.52	14.70
27.38	1.26	6.67	19.80	22.50
26.67	6.84	6.67	11.90	20.00
4.62	4.56	73.44	3.80	20.00
26.67	6.16	5.72	5.40	30.48
60.74	4.70	7.62	6.00	12.98
41.33	9.42	4.76	5.26	21.11
28.89	4.10	20.00	6.67	11.42
73.33	8.82	34.28	8.82	11.67
16.00	27.94	14.28	8.82	25.00
57.34	14.56	6.67	10.48	29.17
19.84	20.00	32.00	12.12	14.17
39.68	2.06	2.86	16.67	10.83
107.66	11.30	7.62	18.62	25.00
38.10	1.08	64.98	23.52	9.70
45.33	25.26	40.00	43.00	44.32
8.89	4.04	28.58	19.00	20.00
26.67	2.02	9.66	4.00	18.28
26.67	43.16	14.50	2.83	20.83
61.48	1.16	9.52	4.00	27.46
74.44	16.18	72.18	2.67	6.67
54.54	14.16	29.42	25.33	26.67
64.00	6.60	24.22	16.20	12.22
55.22	6.00	1.06	6.16	
95.24	2.86	5.40	4.70	
81.33	1.86	12.98	0.00	
67.62	13.24		4.52	
24.00	4.50		5.64	
55.96	2.67		10.78	
124.44	4.00		10.58	
118.52	17.18		18.00	
42.22	2.86		2.50	
62.56	0.00		20.54	
39.82	1.02		2.16	
102.67	10.18		6.48	
86.67	9.10		12.41	
61.84	18.18		10.67	
24.24	2.82		3.88	
76.67			26.67	
53.18			3.04	
60.00			2.90	
16.30			30.67	
43.33			12.38	

able 7. **Eight sets of Japanese commercial yellowfin catches (catch per 2,000 hooks) on which table 2 is based. Each figure represents one day's fishing. The catches were made in the western equatorial Pacific in 1951. (Continued)**

August	August		August		
4°N. L., 158°E. L.	1°N. L., 156°E. L.		1°N. ~~E~~L., 157°E. L.		
29.33	50.48	27.36	24.21	66.67	115.29
43.81	24.00	49.48	43.43	24.12	58.89
19.04	16.41	57.00	12.94	103.53	
17.14	67.02	29.33	67.06	82.41	
13.72	55.18	73.33	74.12	93.47	
86.67	41.14	23.00	178.82	148.00	
55.00	28.58	32.00	47.06	78.32	
28.70	33.33	85.00	37.33	18.63	
40.00	94.66	46.50	76.71	45.71	
28.89	37.94	58.78	113.97	93.33	
69.33	60.52	51.76	82.00	52.38	
37.90	32.39	35.30	89.77	94.44	
54.74	70.52	31.11	38.95	102.67	
41.67	36.92	14.74	86.49	32.00	
51.86	29.41	75.56	68.24	117.33	
23.00	61.33	23.81	52.00	172.00	
80.00	52.22	30.20	46.46	25.92	
66.67	61.54	34.66	30.48	12.97	
50.67	81.00	12.00	95.45	35.35	
114.82	33.52	20.42	21.05	39.39	
45.33	60.96	68.72	40.00	44.76	
40.74	24.76	46.16	38.92	9.14	
107.82	53.33	47.00	35.09	11.58	
64.00	22.86	71.00	54.39	26.67	
15.24	35.36	25.94	94.12	30.67	
55.33	93.33	16.96	90.59	64.86	
53.70	14.28	49.50	82.41	19.30	
	35.24	22.10	36.67	14.91	
	39.04	24.00	7.84	73.68	
	92.64	99.00	32.38	25.55	
	28.10	45.00	73.33	142.10	
	70.40	38.88	25.21	93.00	
	49.00	37.90	30.68	95.55	
	62.00	55.38	80.00	40.00	
	53.68	96.84	56.00	96.89	
	10.81	25.94	171.14	246.00	
	68.42	37.84	61.00	66.67	
	21.02	47.36	92.50	32.88	
	8.89	26.67	37.89	108.27	
	34.00	152.38	62.11	63.81	
	37.00	47.72	162.10	38.89	
	69.00	72.72	27.03	44.00	
	93.00	16.22	22.70	125.00	
	59.00	85.00	70.27	145.00	
	40.00	73.00	91.14	60.95	
	61.62	97.14	16.47	90.59	
	15.15	75.55	43.43	63.81	
	15.91	23.80	38.67	19.05	
	105.68		40.00	50.00	
	23.16		28.95	60.23	

Table 8. POFI longline catches from *Cavalieri* cruise 1 arranged in pairs for the analyses in table 3.

20-basket catches			40-basket catches			80-basket catches			
Number baskets	Number yf		Number baskets	Number yf		Number baskets	Number yf	Number baskets	Numbe yf
15	5	1	30	8	10	60	24 1/	60	44 1/
15	14	2	30	23	10	60	44	68	58
15	13	2	30	21	11	68	14	68	26
17	12	16	34	19	30	68	29	76	36
17	3	6	34	4	8	68	15	76	20
17	7	7	34	10	12	76	8	60	16
17	8	6	34	16	9	72	24	76	23
19	7	5	38	11	23	80	17	80	23
17	2	4	34	3	10	80	21	80	15
19	3	4	38	9	10	80	20	80	9
19	0	2	38	3	5	80	27	80	27
15	2	3	30	5	7	80	24	84	14
18	8	5	36	14	8	80	33	80	61
19	8	6	38	13	9	80	43	80	38
20	4	3	40	12	5				
20	6	7	40	11	12				
20	8	5	40	13	8				
20	1	7	40	5	10				
20	1	6	40	7	13				
20	2	3	40	3	6				
20	6	9	40	13	14				
20	9	3	40	18	9				
20	5	8	40	8	16				
21	3	0	42	7	7				
20	11	15	40	27	34				
20	9	8	40	20	18				
15	3	9							
15	9	8							
15	8	9							
17	7	14							
17	1	2							
17	3	5							
17	8	3							
19	4	18							
17	1	6							
19	6	6							
19	3	3							
15	3	4							
18	6	3							
19	5	3							
20	8	2							
20	5	5							
20	5	3							
20	4	3							
20	6	7							
20	1	3							
20	7	5							
20	9	6							
20	3	8							
21	4	7							
20	16	9							
20	11	10							

1/ These catches have been adjusted to the equivalent of 80 baskets.

Table 9. Pacific Oceanic Fishery Investigations longline catch data, each set subdivided and arranged in pairs for the analyses of table 4. Each catch is based on exactly 20 baskets.

anning cruises 12 and 13		Smith cruise 11		Manning cruise 11	
Set number 1		Set number 2		Set number 3	
0	2	3	0	15	9
4	1	3	3	6	7
2	2	0	2	8	4
2	4	1	3	5	11
10	8	13	10	7	9
4	5	4	10	6	5
0	2	21	17	2	1
7	1	15	11	4	0
0	2	10	10	6	2
2	2	19	18	5	6
5	2	6	13	6	2
3	2	29	15	0	2
1	3	17	13	1	3
2	0	7	4	3	4
1	2	12	11	0	5
7	2	16	15	1	3
5	3	6	9	6	2
2	1	38	33	11	4
1	0	11	20	6	4
2	1	3	2	3	4
3	0	3	1	1	2
5	9	1	0		
7	4	0	1		
7	7	4	1		
1	1				
7	1				
2	3				
11	12				
5	5				
5	3				
1	0				
1	2				
1	0				
1	1				
0	2				

Table 10. Paired Japanese commercial longline catches used in the analyses on table 5. Data are from records of mothership operations in the western Pacific in 1951.

Set number 1		Set number 2	
74	55	18	18
42	63	28	44
40	62	48	50
87	24	24	2
64	95	21	23
56	55	28	26
81	119	26	25
68	53	44	21
124	103	36	55
20	27	70	59
61	57	27	29
108	24	29	21
77	43	12	21
12	27	28	20
27	5	15	14
41	29	7	14
40	38	28	20
6	16	68	73
20	9	46	93
16	27	68	60
45	27	67	72
73	60	41	64
		12	35
		40	21
		44	38
		31	47
		49	30
		11	34
		37	11
		22	53
		19	37
		51	57
		37	42
		21	34
		27	14
		13	8
		23	26
		54	71
		92	29

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ANALYSIS OF CATCHES OF NINE JAPANESE TUNA LONGLINE EXPEDITIONS TO THE WESTERN PACIFIC OCEAN

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The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilizatio practices and as guides for administrative or legislative action. I is issued in limited quantities for the official use of Federal, Sta or cooperating Agencies and in processed form for economy and to avo delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

ANALYSIS OF CATCHES OF NINE JAPANESE TUNA LONGLINE EXPEDITIONS TO THE WESTERN PACIFIC

By

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Pacific Oceanic Fishery Investigations
U. S. Fish and Wildlife Service

Special Scientific Report: Fisheries No. 128

WASHINGTON: DECEMBER 1954

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The tuna resources of the western tropical Pacific are of great interest to the Japanese people, who before the war had begun to exploit them; to the people of the Philippines, Indonesia, and New Guinea, who would like to exploit them; and to the people of Micronesia, who may find in them one of the few things that they can sell. These tuna stocks are also of interest to Americans because some of the islands of the area are presently under U. S. trusteeship and it is continguous to portions of the central Pacific now being explored by the U. S. Fish and Wildlife Service.

Most of the knowledge of these western Pacific resources has been reported in scattered Japanese fishery literature on the prewar activities of Japanese fishermen. Following the war, tuna mothership fishing operations in the equatorial western Pacific (fig. 1) were authorized by the Allied Governments in control in Japan. There were nine of these expeditions between June 1950 and October 1951. Each took the form of a mothership that stored the catch and supplied logistic support to a fleet of relatively small catcher vessels that fished with longlines. Observers from the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service accompanied six of these expeditions and the general observations on the methods, catch, and area fished during these voyages have been published (Shimada 1951a and b, Ego and Otsu 1952, and Van Campen 1952).

In addition to the records obtained by the American observers with the expeditions, the operators were required to maintain a daily log on each of the longline catcher vessels. These logs contain observations on the weather and sea, the number of hooks set each day, the kind of bait used, and the numbers and weights of each of the principal species in the daily catches. Most of the observations were recorded with reasonable accuracy excepting the weights of the fishes, which perforce were estimates on the part of the captains.

The purpose of this paper is to summarize the records with regard to the abundance of the principal species comprising the catch (yellowfin, bigeye, and black marlin), and to examine the relation of abundance to factors in the environment. Since this type of consideration involves interpreting catch rates (usually expressed as catch per 100 hooks) as indexes of abundance, we also examine the possibility that the catch rates might be affected by factors other than abundance, such as the type of bait used and vessel efficiency.

SPECIES OF FISH IN THE CATCHES

The vernacular names of the various species of fish in the catches are used in the text. These are listed below with their usually accepted scientific names.

Yellowfin tuna - *Neothunnus macropterus* (Temminck and Schlegel)
Bigeye tuna - *Parathunnus sibi* (Temminck and Schlegel)
Skipjack - *Katsuwonus pelamis* (Linné)
Albacore - *Germo alalunga* (Bonnaterre)
Black marlin - *Makaira mazara* (Jordan and Snyder)
Pacific white marlin - *Makaira marlina* (Jordan and Hill)
Striped marlin - *Makaira mitsukurii* (Jordan and Snyder)
Pacific sailfish - *Istiophorus orientalis* (Schlegel)
Broadbill swordfish - *Xiphias gladius* (Linné)
Sharks - These are not listed specifically because of inadequate identification in the records.

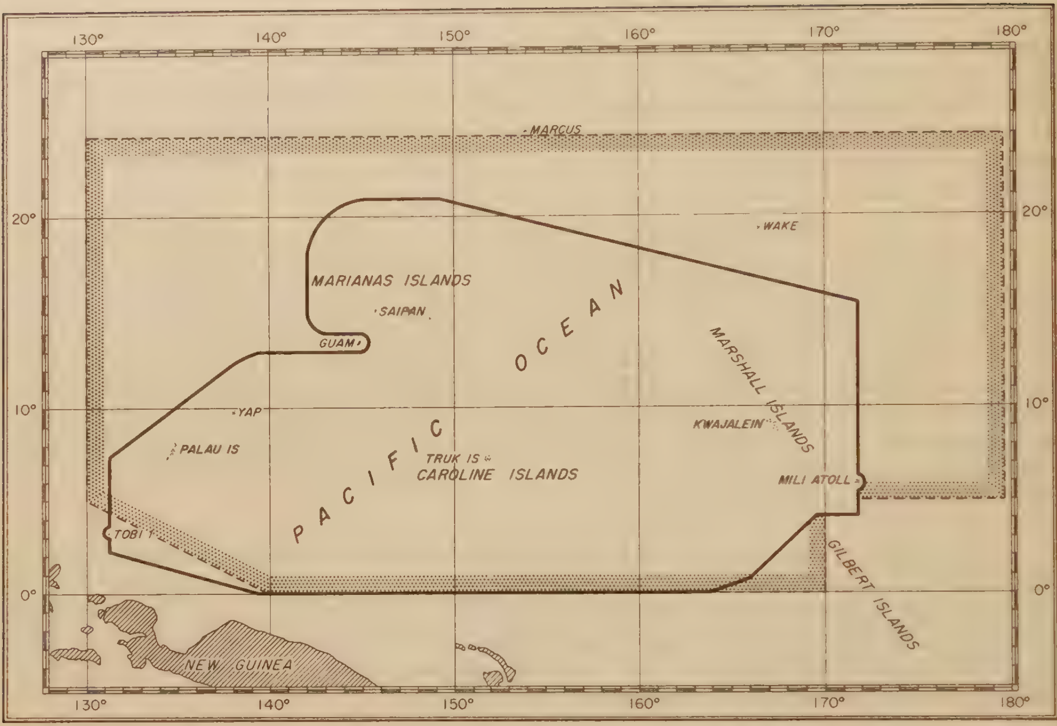
130°
140°
150°
160°
170°
180°
20°
10°
0°
MARCUS
WAKE
MARIANAS ISLANDS
SAIPAN
GUAM
PACIFIC OCEAN
MARSHALL ISLANDS
KWAJALEIN
MILI ATOLL
YAP
PALAU IS
TRUK IS
CAROLINE ISLANDS
TOBI
GILBERT ISLANDS
NEW GUINEA

Figure 1.--Western equatorial Pacific. The dotted-stippled border shows the authorized area for tuna mothership expeditions. The solid black line around the Marianas, Marshall, and Caroline islands shows the U. S. Trust Territory of the Pacific islands. After Shimada (1951a).

EFFECT OF TYPE OF BAIT ON THE CATCH

The capture of a fish on a longline requires that the fish voluntarily strike at a relatively motionless baited hook. Consequently, the possibility is considered that the rate of capture was in part dependent on the type of bait used by the catcher vessels of the mothership expeditions. Three different baits--sardines, *Sardinia melanostica* (Temminck and Schlegel); sauries, *Cololabis saira* (Brevoort); and squid--were used on the expeditions, but because squid were used only incidentally, the comparisons are confined to sauries and sardines.

Quantitative data on the relative effectiveness of sardines and sauries are available from the daily log sheets of each catcher vessel, which list the number of pieces of each type of bait used each day. (Typically, a daily set of gear consisted of around 2,000 hooks and was baited with sardines or sauries or a mixture of the two.) Prior to analysis of these records, each day's fishing was coded on a linear scale of 0 to 10, with 10 representing all sauries, and 0 representing all sardines. The coded catches were then grouped by the relative amount of sauries used as bait as shown in table 1. This summary of all the data indicates that the two baits were about equally effective, although the higher catch rate of yellowfin on 100-percent saury sets is puzzling. However, interpretation of the results requires the assumption that the fishing in all of the 11 categories was similarly distributed in time and space. This probably was not the case, but as a further check we have summarized the catch rates during a single month in each of two limited areas (table 2). We find considerable variations, but for these sets of data the 100-percent saury baitings are not anomalous, and the conclusion that neither bait is superior is confirmed.

Table 1.--Catch per 100 hooks of yellowfin and bigeye tuna arranged by the relative amount of sauries and sardines used as bait (all expeditions combined)

	Percent saury used as bait										
	0	10	20	30	40	50	60	70	80	90	100
Yellowfin	1.97	1.53	2.04	1.18	2.10	1.94	2.03	1.72	1.88	1.88	2.51
Bigeye	0.41	0.76	0.34	0.48	0.57	0.47	0.57	0.68	0.89	0.67	0.61
Thousands of hooks	286	8	169	162	720	4,196	1,232	1,162	828	401	2,071

Table 2.--Summary of the yellowfin tuna catch rates (catch per 100 hooks) by amount of saury used as bait for two limited areas

	Percent saury used as bait										
	0	10	20	30	40	50	60	70	80	90	100
	6°-7°N. latitude, 177°-179°E. longitude, October 1951										
Yellowfin catch rate	0.33	3.24	3.14	0.60	0.70	0.52	0.90	0.48	0.77	-	0.57
Boat/days of fishing	6	1	3	10	12	58	3	14	2	-	5
	1°-2°N. latitude, 160°-165°E. longitude, May 1951										
Yellowfin catch rate	3.42	-	-	-	-	2.47	2.16	0.98	2.24	2.09	2.59
Boat/days of fishing	6	-	-	-	-	12	4	5	5	3	56

Also confirming the conclusion that there is no difference in the catch associated with type of bait are the results of experiments aboard the Sagami Maru, a research vessel from Kanagawa Prefecture, conducted during the seventh mothership expedition (Anonymous 1952). Sardines and sauries were alternated on each hook (5 hooks per basket). Slightly more yellowfin (73 versus 65) and black marlin (75 versus 63) were taken on sardines than on sauries, bigeye and other tunas were taken equally, and more sharks (77 versus 62) were taken on sauries. Thus it appears that the catches made during the nine mothership expeditions can be used as indexes of abundance without regard to the type of bait used on the longline.

RELATIVE CATCHING EFFICIENCY OF THE VESSELS

The mothership expeditions comprised numerous catcher vessels, many of which participated in several expeditions. Analysis of their catches for evidence of geographical and temporal variations in relative abundance would be considerably simplified if it could be shown either that there are no differences in relative efficiency or that such differences as exist are unimportant in magnitude. In longline fishing the total catch made by any vessel is related to the number of hooks fished and the abundance of the fish. This affords ample opportunity for the total catch to be related to such factors as vessel size and the skill of the fishermen, because these affect the amount of gear fished each day. On the other hand, the catch per unit of effort--catch per 100 hooks--should be relatively stable, because once a given number of hooks is placed in the water the number of fish taken on these hooks is largely a function of the availability of fish. There were, however, minor variations in the design of the gear used by the various vessels (Shimada 1951a) and these could conceivably affect the catch per 100 hooks.

In order to test for difference in vessel efficiency, as it affects the catch per unit of effort, a two-way tabulation by vessels and by months was made of the catch rates for each expedition except those of the Nansei Fisheries Company (3, 4, 6, and 9), which were much smaller in size and scope. The catches of yellowfin, comprising about half the total catch, were then studied by analysis of variance (Snedecor 1948). This classification actually affords some statistical control of the catch rate of vessels by area as well as time, because all of the expeditions tended to fish in a group that moved from west to east (and in some of the later expeditions from south to north near the end of their operating period).

The results of the analyses of variance (table 3) show that while there were differences in the catch rates associated with time (and area implied), there were no significant differences associated with vessels except on the fifth expedition. This single exception is puzzling but perhaps can be attributed to failure to completely control area and time in the analysis, a factor that may also account for the several near-significant F values associated with vessels of the first, second, and seventh expeditions. With this in mind, it appears that in general the catch rates of the various vessels do not have to be adjusted for relative efficiency in order to use them interchangeably as indexes of abundance. Further comfort may be taken from the fact that nearly all of the geographical areas and time periods discussed in the balance of this report are represented by the catches of several vessels, tending to average out any differences in efficiency that might exist.

DISTRIBUTION OF THE PRINCIPAL SPECIES AS INDICATED BY THE CATCHES

The longline catches made by the mothership expeditions afford a means of estimating the spatial and temporal distribution of the species of fish comprising the catch. These catches were made during several months of 1950 and 1951 over a wide area (135° E. to 179° E. long., and 1° N. to 10° N. lat.). The present study is confined to the yellowfin tuna, bigeye tuna, and black marlin, in part because together they comprised about 70 percent of the catch, and in part because the yellowfin tuna is a species of considerable economic importance on the American market. Other species that are taken in some numbers by longlining in this region are albacore, skipjack, white marlin, striped marlin, sailfish, broadbill, and sharks. While the catch rates of these species have not been subjected to analysis, they are listed in the tables of catch rates in the appendix.

Table 3.--Analyses of variance of the catch of yellowfin tuna of the mothership expeditions (data in table 12, appendix)

Expedition	Source of variation	Degrees of freedom	Sum of squares	Mean square	F	F, P = 0.05
1	Vessels	19	6.2217	0.3275	1.78	1.85
	Months[1]	2	1.1801	0.5901	3.20	3.25
	Discrepancy	38	7.0087	0.1844	--	--
	Total	59	14.4105	--	--	--
2	Vessels	11	6.5186	0.5926	2.05	2.26
	Months[2]	2	1.4735	0.7368	2.54	3.44
	Discrepancy	22	6.3735	0.2897	--	--
	Total	35	14.3656	--	--	--
5	Vessels	12	7.5790	0.6316	5.35	2.18
	Months[3]	2	3.3242	1.6621	14.07	3.40
	Discrepancy	24	2.8346	0.1181	--	--
	Total	38	13.7378	--	--	--
7	Vessels	21	11.6621	0.5553	1.57	1.82
	Months[4]	2	45.7537	22.8768	64.48	3.22
	Discrepancy	42	14.9010	0.3548	--	--
	Total	65	72.3168	--	--	--
8	Vessels	20	4.0191	0.2010	0.36	1.99
	Months[5]	2	37.5728	18.7864	34.08	3.23
	Discrepancy	40	22.0508	0.5513	--	--
	Total	62	63.6427	--	--	--

[1] June to August, 1950
[2] July to September, 1950
[3] April to June, 1951
[4] June to August, 1951
[5] August to October, 1951

It should be emphasized that catches made by longline fishing do not represent cross sections of the population. Rather these catches, particularly in the instance of the tunas, represent the larger, older individuals in the population, and of course only that portion of the latter that occupy subsurface levels. This topic is treated in some detail in the section immediately following the discussion of numerical abundance.

The analysis of the expeditions' catch records was facilitated by utilizing IBM punch cards, requiring the adoption of a coding system. Preliminary inspection indicated that the variation in catch rate was more closely related to latitude than to longitude, and for this reason all catches were assigned to blocks of 1° of latitude and 5° of longitude. Temporally, the catches were coded by month and by year. This grouping has the disadvantage of obscuring individual catches, but it would have been impracticable to handle the approximately 6,000 individual daily catch records without it.

Variation in the catch with longitude and time

We shall first consider the variation in the longline catch rates of yellowfin, bigeye, and black marlin as they are related to longitude and time, deferring consideration of variation with latitude. Working statistical control of latitude was achieved in the following manner. Trial latitudinal plots of individual longitudes indicated that the catch rates were relatively constant between 1° and 5° N. latitude, in that there was relatively little variation within these bounds as compared to the variation between this zone and the area to the north. Confining the consideration of longitudinal and temporal variation in catch rates to the relatively restricted latitudes bounded by 1° and 5° provided partial control of latitude. Additional statistical control was effected by taking advantage of the fact that at nearly all longitudes there was some fishing at each latitude between the limits of 1° and 5° N. This was done by computing the average catch rate for each of the four degrees of latitude and computing the unweighted mean catch rate of the four samples. The end result was a catch rate representative of an area of the ocean surface that is 5° of longitude in length and 4° of latitude in height for 1 month of 1 year.

The catch rates derived by this method are shown in table 4 arranged by species, year, month, and longitude. Each of the three species--yellowfin, bigeye, and black marlin--will be considered separately because, as will be shown later, there is little or no relationship between the presence of bigeye and the presence of yellowfin, and there is no reason to expect the presence or absence of marlin to be in anyway related to the presence of the tunas.

The catch rates of the yellowfin (table 4) show that during some months, e.g., July of 1950, they were more abundant at the eastern end of the area than at the western end. During other months, e.g., September 1951, the gradient appears to have been reversed. Of the three months for which good records were obtained in both 1950 and 1951 (June, August, and September), two show a reversal of the gradients between the two years. For these reasons it seems likely that the longitudinal gradients, even if real, are not caused by regularly recurring phenomena.

Averaging all the unweighted monthly catches for each longitude appears to eliminate these apparently transient differences associated with longitude. If this is done, the average catches for the four zones of longitude east of 150°E., for which sampling is reasonably well stratified, have a range of only 2.20-2.50 yellowfin per 100 hooks. If the area under consideration is extended west to 140°E. (the samples to the west are not as well stratified as those to the east of 150°E.), the range of variation is increased to only 1.84-2.50, or a 36-percent difference between the highest and the lowest values. This is a remarkably constant abundance for any species of animal to maintain over a 2,000-mile range (140°-170°E.), and probably means that the environment is highly uniform over that range.

The figures in parentheses are the number of boat days of fishing on which each catch rate is based

Species	Year	Month	Longitude						
			135°-140°E.	140°-145°E.	145°-150°E.	150°-155°E.	155°-160°E.	160°-165°E.	165°-170°E.
Yellowfin tuna	1950	June	--	2.31 (107)	2.64 (71)	--	--	--	--
		July	--	2.08 (19)	1.78 (139)	2.16 (238)	2.66 (88)	2.78 (51)	--
		Aug.	--	0.90 (2)	1.66 (3)	1.61 (7)	2.30 (412)	2.45 (104)	2.40 (177)
		Sept.	--	--	--	--	--	1.85 (53)	2.56 (176)
		Dec.	4.18 (83)	4.02 (4)	--	--	--	--	--
	1951	Feb.	--	--	--	2.46 (1)	3.00 (166)	3.41 (39)	--
		Mar.	2.54 (8)	1.82 (28)	1.45 (2)	--	--	--	--
		Apr.	4.17 (1)	1.82 (12)	1.66 (105)	1.90 (159)	2.70 (72)	--	--
		May	--	--	--	2.56 (40)	1.82 (181)	1.84 (214)	4.31 (2)
		June	--	--	--	2.97 (124)	2.87 (183)	3.76 (85)	--
		July	--	--	--	--	--	2.47 (152)	2.24 (252)
		Aug.	--	--	--	2.63 (24)	2.31 (254)	1.90 (42)	--
		Sept.	--	--	--	2.27 (6)	2.24 (118)	2.03 (202)	1.52 (130)
		Oct.	--	--	--	--	--	--	1.72 (44)
Bigeye tuna	1950	June	--	0.28 (107)	0.29 (70)	--	--	--	--
		July	--	0.23 (19)	0.32 (139)	0.36 (238)	0.40 (88)	0.45 (51)	--
		Aug.	--	0.25 (2)	0.38 (3)	0.19 (7)	0.30 (412)	0.37 (104)	0.65 (177)
		Sept.	--	--	--	--	--	0.18 (53)	0.19 (176)
		Dec.	0.44 (83)	0.58 (4)	--	--	--	--	--
	1951	Feb.	--	--	--	0.35 (1)	0.37 (166)	0.34 (39)	--
		Mar.	0.44 (8)	0.40 (28)	0.42 (2)	--	--	--	--
		Apr.	0.83 (1)	0.45 (12)	0.55 (105)	0.49 (159)	0.39 (72)	0.39 (1)	--
		May	--	--	--	0.76 (40)	0.62 (181)	0.56 (214)	1.06 (2)
		June	--	--	--	0.91 (124)	0.81 (183)	0.65 (85)	--
		July	--	--	--	--	--	0.82 (151)	1.03 (252)
		Aug.	--	--	--	0.64 (24)	0.52 (254)	0.74 (42)	--
		Sept.	--	--	--	0.27 (6)	0.53 (118)	0.79 (202)	0.66 (130)
		Oct.	--	--	--	--	--	--	0.46 (2)
Black marlin	1950	June	--	0.50 (107)	0.53 (70)	--	--	--	--
		July	--	0.56 (19)	0.53 (139)	0.53 (238)	0.55(88)	0.64 (51)	--
		Aug.	--	0.60 (2)	0.48 (3)	0.33 (4)	0.47 (412)	0.86 (104)	0.83 (177)
		Sept.	--	--	--	--	--	0.54 (53)	0.56 (176)
		Dec.	--	0.40 (83)	0.17 (4)	--	--	--	--
	1951	Feb.	--	--	--	0.15 (1)	0.66 (166)	0.47 (39)	--
		Mar.	0.19 (8)	0.25 (28)	0.21 (2)	--	--	--	--
		Apr.	0.97 (1)	0.19 (12)	0.27 (105)	0.40 (159)	0.50 (72)	0.33 (1)	--
		May	--	--	--	0.34 (40)	0.36 (181)	0.39 (214)	0.83 (2)
		June	--	--	--	0.27 (124)	0.36 (183)	0.41 (85)	--
		July	--	--	--	--	--	0.30 (152)	0.45 (252)
		Aug.	--	--	--	0.47 (24)	0.32 (254)	0.30 (42)	--
		Sept.	--	--	--	0.52 (6)	0.34 (118)	0.31 (202)	0.35 (130)
		Oct.	--	--	--	--	--	--	0.73 (44)

The seasonal distribution of the longline yellowfin catches shows more prominent variation than the longitudinal distribution. For instance, June showed a catch peak irrespective of longitude (table 4). A second peak during the December-February period is also evident. This is shown graphically in figures 2 to 4. Figure 2 is a plot of the monthly catches at 160°-165°E. longitude, figure 3 is a plot of the catches at 155°-160°E. longitude, and figure 4 shows the mean catch by month irrespective of longitude. (The two longitudes illustrated in figs. 2 and 3 were chosen because they were the best represented in time.) It is of interest to note that the shapes of the curves for the two longitudes are nearly identical, and that these in turn resemble the curves for all longitudes combined. Furthermore, in each of the three figures there is considerable similarity in the shapes of the curves for the two years 1950 and 1951. This relative stability of the pattern of seasonal variation in this portion of the western Pacific indicates that the pattern is real, and furthermore, because it is apparently repeated during two years, the pattern is probably the result of regularly recurring changes in the tuna population. Precisely what factors induce these changes in the population level is unknown.

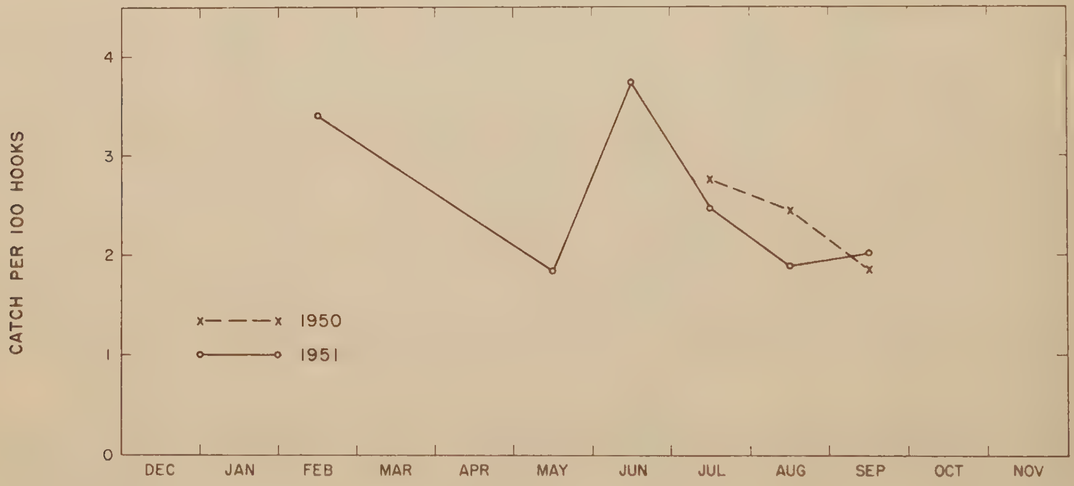

Figure 2.--Yellowfin tuna catch per 100 hooks by months for 1°-5°N. latitude, 160°-165°E. longitude. Points obtained from table 4.

The longitudinal distribution of bigeye tuna in the area under consideration resembles that of the yellowfin in that the differences in abundance associated with longitude appear to be slight and inconsistent (table 4). This is a further indication that the environment over the area under consideration is relatively uniform insofar as its east-west component is concerned.

The seasonal distribution of bigeye (fig. 5) bears a general similarity to that of the yellowfin in that there appear to be two peaks of abundance, one in June-July-August, and one in December. The latter peak is not well developed as it was in the instance of the yellowfin, but the July peak is very prominent, particularly in 1951. The 1950 peak that corresponds to the July 1951 peak is well developed but occurred 1 month later, in August, and in magnitude is only half as large as the 1950 maximum. As in the instance of the yellowfin, the general regularity of the seasonal distribution of bigeye in the western Pacific just north of the Equator suggests the operation of cyclic phenomena.

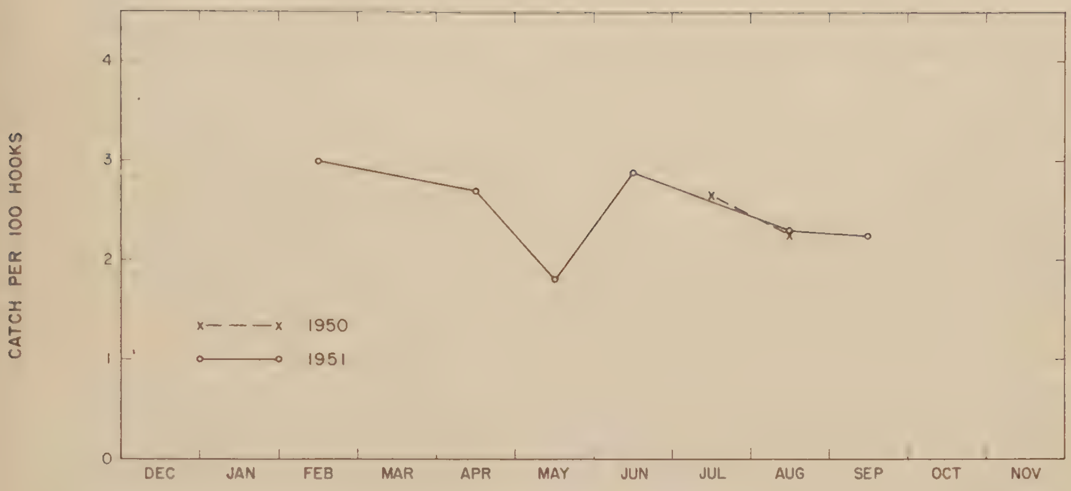

Figure 3.--Yellowfin tuna catch per 100 hooks by months for 1°-5°N. latitude, 155°-160°E. longitude. Points obtained from table 4.

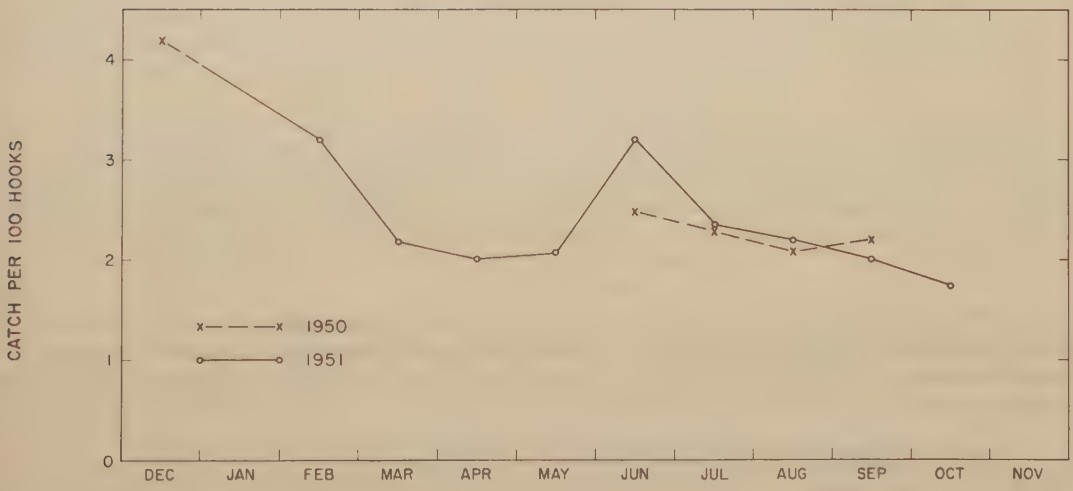

Figure 4.--Yellowfin tuna catches per 100 hooks by months for 1°-5°N. latitude, 135°-170°E. longitude. Points obtained from table 4 by averaging the unweighted mean catch rates, excluding those based on less than 3 days.

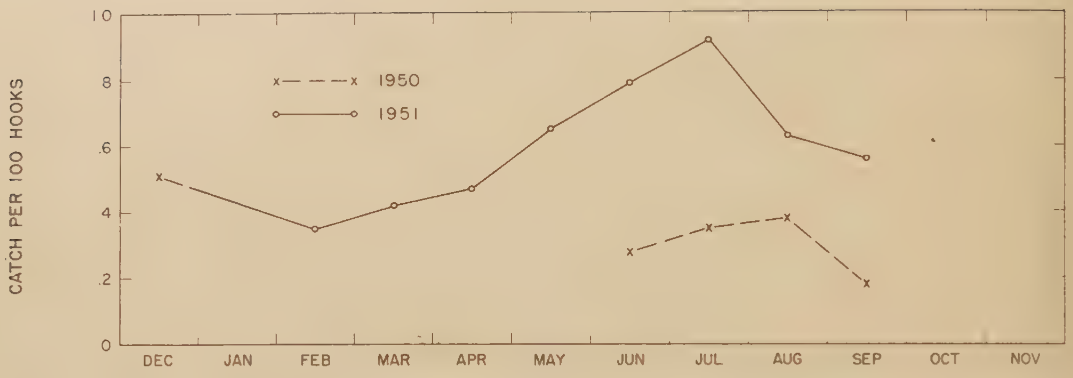

Figure 5.--Bigeye tuna catches per 100 hooks by months, 1°-5°N. latitude, 135°-170°E. longitude. Points obtained from table 4 by averaging the unweighted mean catch rates, excluding those based on less than 3 days.

Black marlin catches in the mothership area fail to show a recognizable pattern of variation in abundance with respect to longitude (table 4). With respect to time there do not appear to be the well marked peaks and valleys of abundance (fig. 6) evidenced by the two species of tuna. However, the catch rate in 1951 fell to about one-half that of 1950 (fig. 6).

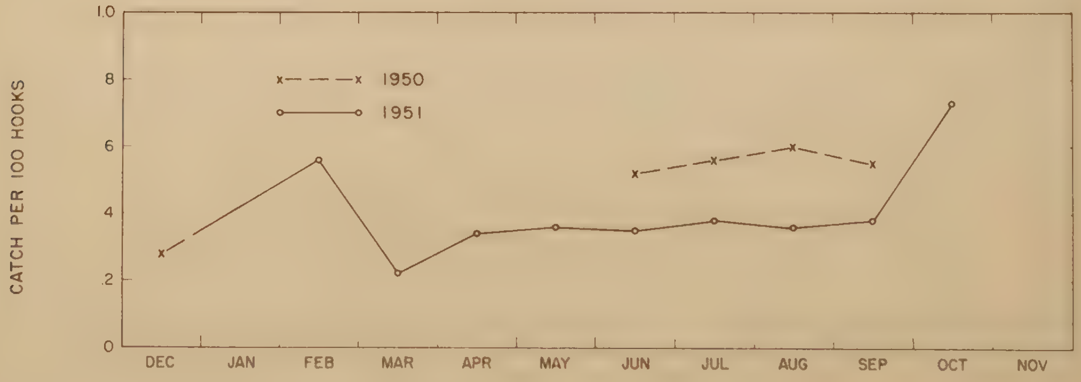

Figure 6.--Black marlin catches per 100 hooks by months, 1°-5°N. latitude, 135°-170°E. longitude. Points obtained from table 4 by averaging the unweighted mean catch rates, excluding those based on less than 3 days.

Examination of the relative abundance of yellowfin, bigeye, and black marlin with respect to time and longitude in a narrow band north of the Equator in the western Pacific has shown that with respect to longitude there is little difference in abundance between the limits of 135°-169°E. longitude. Therefore, insofar as the relative abundance of a species of animal can be regarded as an indicator of the constancy of the environment, this 2,000-mile zone of water just north of the Equator must be relatively uniform in character. Analysis of the catches of these same species with respect to time showed that the populations of two of them were markedly different at different periods of the year, but the black marlin did not vary greatly in abundance from month to month. It does not seem likely that the absolute number of yellowfin and bigeye in the western Pacific fluctuates rapidly from month to month, indicating that the fluctuations are a response to changes in the local environment stimulating ingress or egress of tuna. These changes could occur within the area of study, or could occur outside the area.

Latitudinal variation in catch rates

In the central Pacific the abundance of tuna has been found to vary significantly with latitude in the vicinity of the Equator (Murphy and Shomura 1953). For this reason the catches were tabulated by each degree of latitude instead of the 5° groups used in the case of longitude. Before examining the variation in catches with respect to latitude it should be necessary to take into account variation associated with longitude and time. However, in this instance it did not appear necessary to eliminate variations in catch rate associated with longitude because these variations are considerably smaller than those associated with latitude and time and, empirically, latitudinal plots of catches by both longitude and time resulted in the same latitudinal distribution as those plotted against time alone.

A series of panels representing the variation in longline catch rates of yellowfin, bigeye, and black marlin associated with latitude is given in figure 7. These panels represent each month in which there was a substantial amount of fishing in the area between 1°-10°N. latitude. The catches from longitudes east of 170°E. are separated from the remaining longitudes because there was no fishing between 1° and 5°N. latitude, and consequently no evidence that the catch patterns can be regarded as similar to those of the sections farther west during the same months.

The most striking feature common to all of the panels in figure 7 is the relatively greater abundance of yellowfin tuna at latitudes near the Equator. During some months the center of abundance appeared to be a few degrees north of the Equator, but during seven months abundance appeared to be increasing at the most southerly penetration of the fishing fleets (1°N. lat.). This carries the implication that abundance was even greater to the south, but unfortunately fishing data are not available.

The latitudinal distribution of bigeye tuna appears to be independent of yellowfin (fig. 7). Instead of being most abundant at or near the Equator, the bigeye appear most abundant north of 5°-6°, although in no instance does the magnitude of the peak bigeye catch approach that of the peak yellowfin catch.

Further indication that the latitudinal distributions of yellowfin and bigeye are independent of each other is obtained from a plot of the bigeye catches for each degree of latitude against the yellowfin catches for the same areas (fig. 8). This scatter diagram reveals an utter lack of systematic relationship between the catches. The lack of any relationship is a reflection of the latitudinal variation shown in figure 7, in which yellowfin are shown to vary rather markedly with latitude and bigeye only slightly. A scatter diagram of bigeye catch rates against yellowfin catch rates for individual fishing stations (fig. 9) also resembles figure 8 in that there is no evidence of relationship. From these considerations we may infer that the distribution of the two species is not dependent on the same set of ecological factors, and that within a particular area the two species do not school together. The same situation seems to prevail in the central Pacific (Murphy and Shomura 1953).

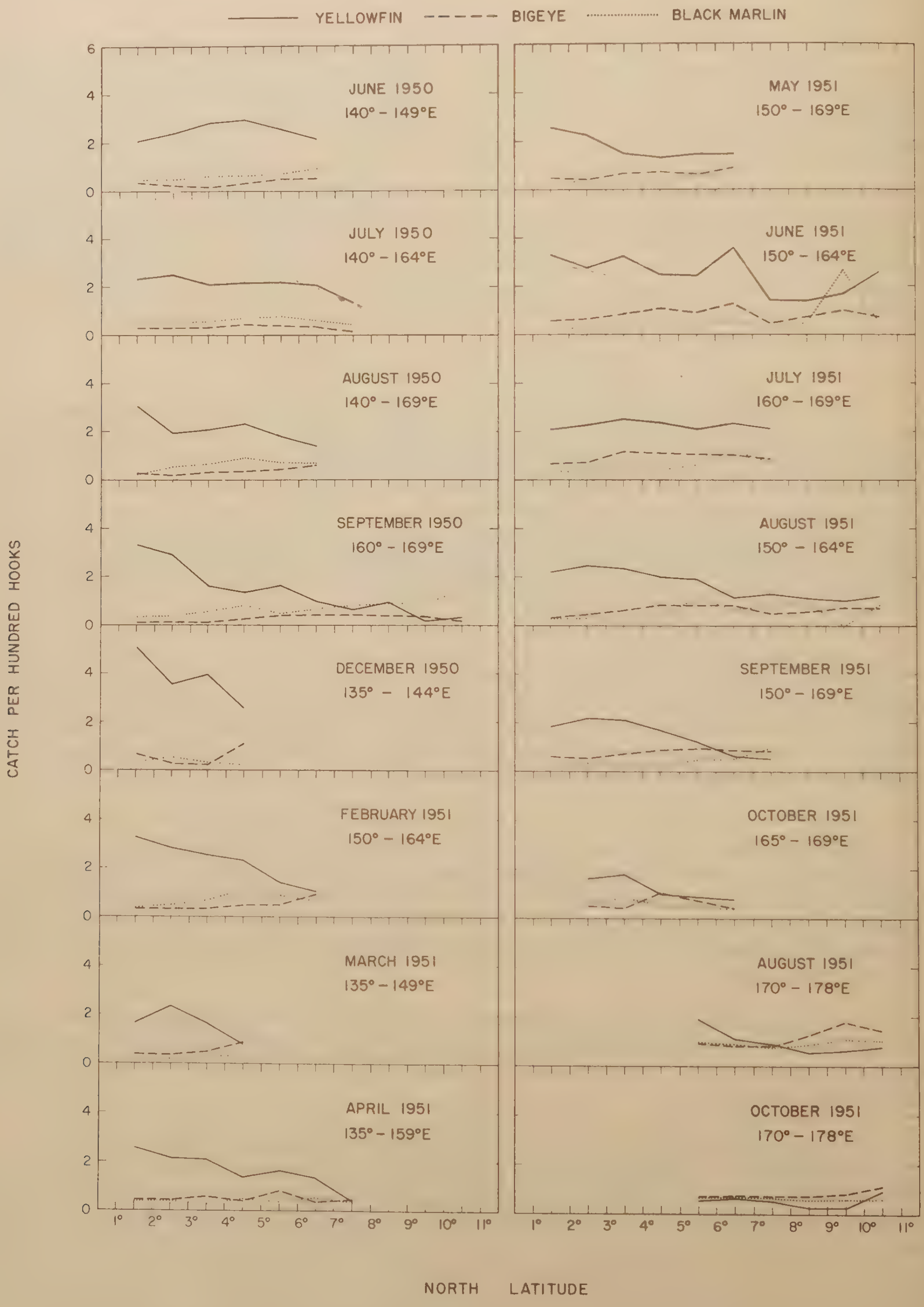

Figure 7.--Latitudinal variation in the catch rates of yellowfin tuna, bigeye tuna, and black marlin by months and years.

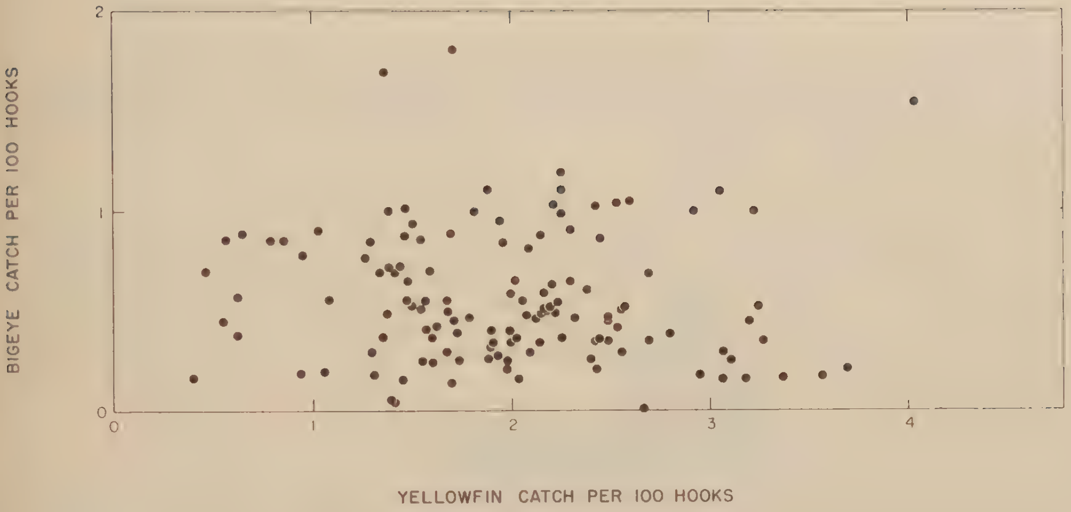

Figure 8.--Catch rate of yellowfin tuna plotted against catch rate of bigeye tuna for each 1° of latitude by 5° of longitude block for all available data.

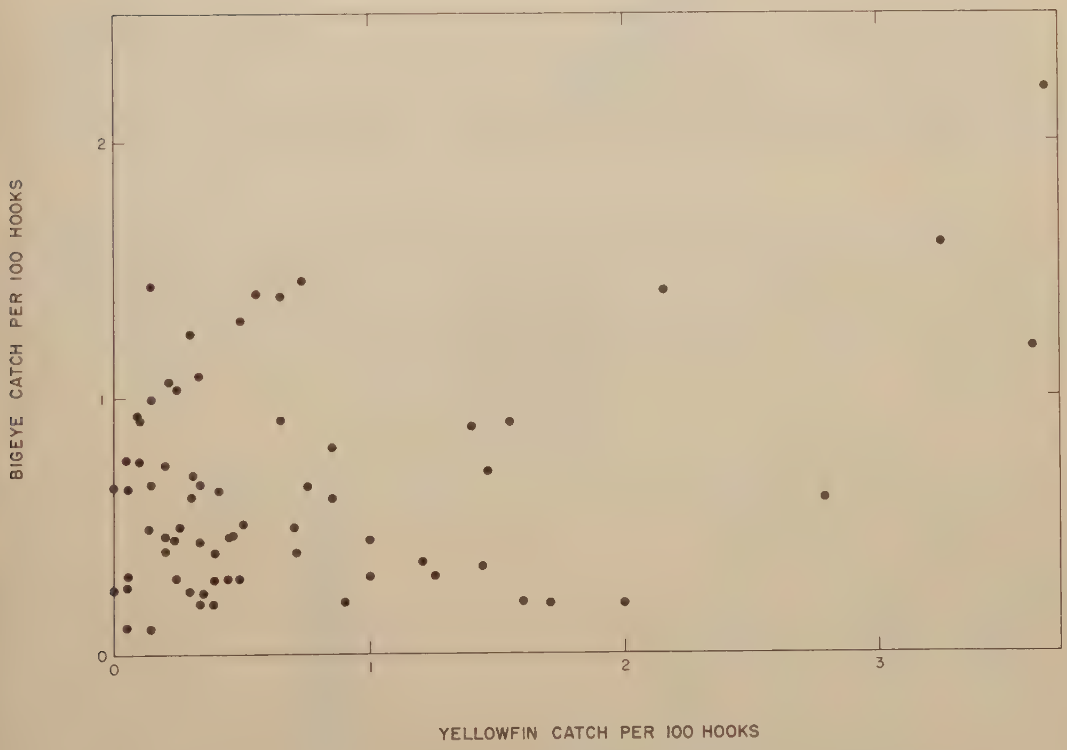

Figure 9.--Yellowfin catch rate plotted against bigeye catch rate for stations fished at 6°-7°N., 178°-179°E. in October 1951.

The latitudinal distribution of black marlin (fig. 7) resembles the bigeye distribution in that there is in general little variation in catch rate with latitude. There is, however, a slight tendency for the catch rates to rise to the north, and in this respect also the black marlin distribution resembles that of the bigeye.

In summary, the catch rate of the yellowfin tuna taken by longlining during the mothership expeditions appears to be largely independent of the catch of bigeye and black marlin, which tend to be more abundant to the north. Yellowfin exhibit a striking tendency to be more abundant in the immediate vicinity of the Equator, with the center of abundance varying in location from 3°-4°N. latitude to a location apparently on or south of the Equator. These variations in the location of yellowfin abundance appear to be related to time, but there is no systematic pattern common to both years (1950 and 1951).

SIZE FREQUENCIES OF TUNAS

The size frequencies of the tunas taken on the motherships provide a means of detecting intrinsic changes in the fish population from area to area and from time to time, and they describe the segment of the population sampled by the fishing method employed. Technologically they are of interest because they tell the fisherman how many fish he must catch to achieve a particular tonnage, and they afford the canner a means of estimating the special problems involved in processing fish from that area.

Aboard the motherships an attempt was made to measure[1] random samples of the catches of tunas as they were unloaded from the catcher vessels. The attempt at randomness was not entirely successful as small yellowfin and bigeye tuna were handled separately from the larger fish in the same load, resulting in a tendency to measure a greater proportion of the fish less than 90 cm. in length. This is not regarded as a serious objection as only 4 percent of the total yellowfin measured and 9 percent of the total bigeye measured were less than 90 cm. in length.

Turning to the yellowfin length frequencies (fig. 10 and table 5), it is evident that there is considerable variation from sample to sample in the mean length (113-129 cm.) and modal class (or classes), but this variation does not appear to be systematically related to time or space. In addition, length frequencies of fish captured by longline in the same general area in 1940 (table 6, Ikebe 1941) indicate there has been little material change in the size composition of the population during the intervening 10 years in that the mean falls within the range noted above.

The restricted size range of yellowfin in the longline catches (fig. 10) is of further interest for it indicates that this method of fishing is sampling only the larger mature fish (90 percent weigh between 40 and 126 pounds) that must surely be in a minority considering the population as a whole. The smaller, and theoretically more abundant, yellowfin tuna almost entirely lacking in longline catches are taken at the surface by trolling and pole-and-line fishing. In the Hawaiian Islands these surface-caught fish range from 50 to 90 cm. (Moore 1952). In the equatorial region south of the Hawaiian Islands they range from 50 to 150 cm. with a mode around 85 cm. Trolling in the northern Marshall Islands at 10°N. latitude, 170°E. longitude, just north of the area from which the mothership samples were taken, yielded the catches of medium-sized yellowfin shown in table 7. These data show quite clearly that gear fishing the deeper waters (longlines) takes a very different portion of the population than do surface fishing techniques. The different sizes of the fish may be the result of a real ecological separation of the large and small fish or may be simply the result of gear selection. At any rate it is evident that the several methods presently available do not furnish samples of the population or populations that are random with respect to the sizes of individuals.

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[1] Total length (Marr and Schaefer 1949). Actually this is a fork length measured from the tip of the upper jaw to the center of the tail.

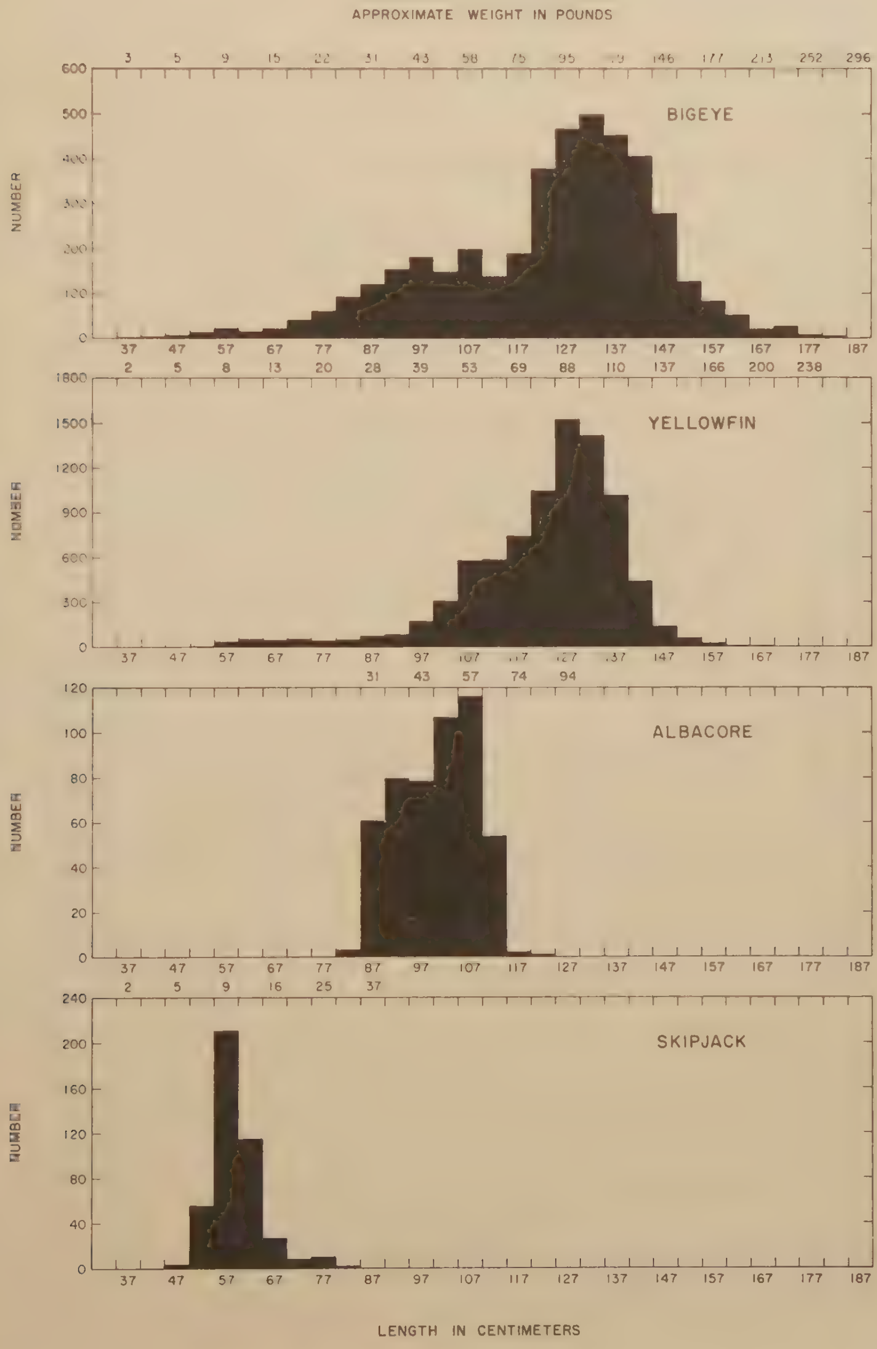

Figure 10.--Length frequencies of the four species of tuna commonly taken during the mothership operations. For convenience a pound scale is provided above each polygon.

Table 5.--Length frequencies of samples of yellowfin tuna from the nine mothership expeditions (East longitude)

Length (cm)	June 1950 140°-150°	July 1950 140°-150°	Aug. 1950 150°-160°	Dec. 1950 134°-141°	Feb. 1951 156°-161°	Mar. 1951 138°-150°	Apr. 1951 147°-155°	May 1951 150°-161°
52	1	-	-	-	-	-	-	-
57	1	-	1	-	-	-	3	-
62	6	2	2	2	-	-	1	-
67	5	2	5	1	-	-	-	2
72	5	2	10	10	-	1	3	1
77	14	3	5	6	-	-	-	1
82	3	0	15	4	-	5	-	3
87	10	5	23	7	-	9	2	1
92	10	1	12	4	1	12	3	6
97	50	3	8	4	1	27	18	4
102	152	8	9	5	2	25	24	19
107	320	22	24	9	16	31	23	15
112	180	16	26	26	16	16	23	16
117	168	10	38	42	30	19	25	28
122	306	21	89	23	66	31	37	37
127	395	42	238	20	99	63	68	80
132	280	54	215	16	150	63	92	105
137	124	65	121	11	86	21	42	64
142	26	31	31	4	19	9	16	29
147	14	5	23	1	2	-	1	2
152	2	2	8	-	1	-	1	1
157	-	1	-	-	0	-	-	1
162	-	-	-	-	2	-	-	-
167	-	-	-	-	2	-	-	-
Mean	119	126	125	113	129	118	122	126
Estimated mean wt. (lb.)	72	86	84	62	92	70	78	86

Table 5.--Length frequencies of samples of yellowfin tuna from the nine mothership expeditions (East longitude) (cont'd)

Length (cm)	May 1951 158°-164°	June 1951 153°-161°	June 1951 154°-162°	July 1951 162°-170°	Aug. 1951 168°-175°	Sept. 1951 155°-161°	Sept. 1951 159°-171°	Oct. 1951 164°-179°	Total
52	-	-	1	-	3	-	-	-	5
57	-	1	9	3	4	10	1	-	33
62	1	-	1	7	6	13	7	2	50
67	-	2	1	4	5	2	11	6	46
72	1	1	2	4	4	1	2	3	50
77	-	4	0	3	0	2	1	2	41
82	2	3	1	5	3	1	1	1	47
87	2	0	0	4	1	0	3	3	70
92	3	13	1	9	6	0	1	3	85
97	5	17	8	11	6	0	3	3	168
102	5	20	13	12	3	1	8	4	310
107	12	12	17	29	12	12	16	11	581
112	12	13	16	37	22	60	84	23	586
117	20	18	24	47	21	82	132	44	748
122	46	42	19	62	31	70	115	56	1050
127	51	51	44	80	39	91	104	61	1526
132	61	50	36	51	38	77	78	51	1417
137	47	34	43	60	70	86	80	66	1020
142	25	18	26	53	55	37	36	27	442
147	5	3	14	23	15	10	13	5	136
152	1	-	4	22	6	6	2	1	57
157	-	-	3	8	5	1	-	1	20
162	-	-	-	2	2	1	-	-	7
167	-	-	-	2	-	-	-	-	4
Mean	126	121	123	124	125	123	122	124	
Estimated mean wt. (lb.)	86	76	80	82	84	80	78	82	

Table 6.--Length frequencies of yellowfin tuna from the Equatorial Countercurrent area, 2°30' - 5°28'N., 135°14' - 165°40'E.; November 1940 (reported by Ikebe 1941)

Length (cm)	Frequency
92	--
97	2
102	9
107	30
112	15
117	19
122	43
127	46
132	15
137	6
142	1
Mean	120
Estimated mean weight (lbs.)	74

Table 7.--Length frequencies of troll-caught yellowfin tuna from the northern Marshall Islands (after Marr 1951)

Length (cm)	Frequency
52	23
57	27
62	22
67	27
72	12
77	11
82	5
87	5
92	9
97	4
102	5
107	2
112	3
117	2
122	1
Mean	70
Estimated mean weight (lbs.)	15

Length frequencies of bigeye tuna taken during the nine mothership expeditions are given in table 8 and figure 10. As in the instance of yellowfin tuna, only the larger fish (50-145 pounds) are well represented, and the individual samples differ in their means (111-132 cm.) and modal group or groups, though without any evident systematic order in respect to either time or space. The longline-caught bigeye in this region are some 20 pounds heavier than the yellowfin. A difference in the same direction and of greater magnitude was noted in the central Pacific (Murphy and Shomura 1953).

The bulk of the albacore catch were 86-112 cm. in total length (30-65 pounds) (table 9, fig. 10), which contrasts sharply with, for instance, catches of 65-90 cm. (10-35 pounds) off San Pedro, California (Brock 1943). These small albacore taken off the Pacific coast of the U. S. are found at the surface, whereas albacore have not been reported at the surface in equatorial waters. Perhaps the large, adult fish tend to occupy cooler, deeper strata of water in the tropics, waters comparable in temperature to those at the surface in more northern latitudes.

The skipjack taken during the mothership expeditions are represented in the two length frequencies in table 10 and one in figure 10. The length distribution of the skipjack appears to represent what might be expected if the sampling were done from a complete population, one in which each size category was proportionally represented, and with gear selection precluding the capture of the smallest individuals[2]. There is considerable increase in size of the second skipjack length frequency (table 10). The displacement of approximately 4 cm. in about 3-1/2 months elapsed time may represent growth.

The skipjack length distribution (fig. 10) provides a strong argument against attributing the shape of the yellowfin, bigeye, and albacore length frequencies to gear selection but rather indicates habitat selection by size; this is based on the fact that the upper end of the skipjack distribution almost coincides with the lower end of the distributions of these species. It might be argued that small yellowfin, bigeye, and albacore are not taken because they feed on a group of organisms different from those the larger individuals feed on. However, Reintjes and King (1953) have shown that the foods taken are not related to the size of the yellowfin within the limits of the fish sizes taken by trolling, livebait fishing, and longlining. These observations permit the tentative conclusion that there is considerable habitat selection, possibly both vertical and horizontal, between small and large tuna, with the possible exception of the skipjack. The large, mature yellowfin, bigeye and albacore tend to occupy sub-surface waters in the tropics and small, immature fish tend to occupy the surface waters, resulting in longline catches of yellowfin, bigeye, and albacore being composed in the main of large fish. There may also be a considerable horizontal displacement between small and large yellowfin and bigeye tuna, and there certainly is in the instance of albacore, small individuals almost never being taken in the tropics in the central and western Pacific and never having been recorded at the surface there.

RELATION OF YELLOWFIN CATCH RATES TO THE ENVIRONMENT

The catch rates of yellowfin tuna experienced by the mothership expeditions have been shown to vary significantly with time and with latitude. Presumably these changing rates reflect changing local abundance, and it seems reasonable to assume that these are a reflection of changes in the environment, particularly in view of the lack of evidence for change in the absolute magnitude of the population. Of necessity we confine the bulk of our discussion to the persistently greater abundance of yellowfin tuna in the immediate vicinity of the Equator, restricting our discussion of time variation to speculation on the causes of an apparent decline in abundance between the pre- and post-World War II periods.

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[2] Longline gear utilizes relatively large hooks and baits designed to catch large tuna and marlin. It would not be expected to be an efficient sampling tool for fish less than about 55 cm. in length (about 8 pounds).

Table 8.--Length frequencies of samples of bigeye tuna measured during the mothership expeditions (East longitude)

Length (cm)	June 1950 140°-150°	Feb. 1951 156°-161°	Apr. 1951 138°-150°	May 1951 150°-161°	May 1951 158°-164°	June 1951 153°-161°	June 1951 154°-162°	July 1951 162°-170°	Aug. 1951 168°-175°	Sept. 1951 155°-161°	Oct. 1951 159°-171°	Oct. 1951 164°-179°	Total
37	-	-	-	-	-	-	-	-	2	-	-	-	2
42	-	-	1	-	-	-	-	-	3	-	-	-	4
47	-	-	-	-	-	-	-	3	3	-	-	-	6
52	-	-	-	-	1	-	-	4	7	1	-	-	13
57	2	-	1	-	2	-	3	4	2	8	-	-	22
62	-	-	1	-	1	-	-	2	2	7	2	-	15
67	2	1	4	2	2	2	1	2	-	3	3	-	22
72	1	4	11	4	5	2	2	1	1	6	4	1	42
77	1	5	16	4	7	3	4	6	-	11	4	1	62
82	4	7	2	4	4	7	5	8	4	26	24	-	95
87	1	2	3	5	8	7	5	10	5	32	38	6	122
92	1	7	10	3	7	9	4	6	3	42	52	12	156
97	1	13	8	10	5	10	6	13	4	42	51	19	182
102	3	5	20	8	15	12	11	13	3	17	28	15	150
107	17	1	1	12	13	17	6	25	7	35	49	17	200
112	18	5	2	4	14	14	7	10	11	11	27	16	139
117	15	12	22	18	27	15	10	14	7	13	24	14	191
122	28	9	17	30	55	34	32	39	19	50	51	16	380
127	31	11	37	28	72	29	25	58	31	52	58	36	468
132	42	12	33	38	62	33	29	47	47	41	65	51	500
137	31	11	27	21	74	21	30	60	24	44	64	48	455
142	15	11	17	33	58	39	21	51	44	23	50	45	407
147	9	15	16	20	40	20	14	48	32	6	23	37	280
152	4	7	5	5	15	9	7	19	10	3	18	26	128
157	2	8	9	5	6	6	3	8	12	1	14	9	83
162	1	3	2	-	1	-	3	8	14	1	6	13	52
167	-	1	-	-	2	-	1	1	3	-	3	8	18
172	-	-	-	-	-	-	1	2	9	-	3	9	24
177	-	-	-	-	-	-	-	2	-	-	-	4	6
182	1	-	-	-	-	-	-	-	-	-	-	4	4
Mean	125	122	119	125	127	124	124	126	129	111	118	132	
Estimated mean wt. (lbs.)	91	85	79	91	95	89	89	93	100	64	77	107	

Table 9.--Length frequencies of albacore measured during the mothership expeditions (East longitude)

Length (cm.)	July 1950 162°-170°	Aug. 1950 168°-175°	Sept. 1951 155°-161°	Sept. 1951 159°-174°	Oct. 1951 164°-179°	Total
84	-	-	2	1	-	3
85	-	1	2	1	-	4
86	-	2	3	2	-	7
87	1	3	6	4	-	14
88	-	1	10	8	-	19
89	-	1	9	7	-	17
90	-	1	4	8	1	14
91	2	1	3	6	1	13
92	2	2	6	4	2	16
93	1	-	6	7	1	15
94	6	1	7	7	1	22
95	4	3	1	5	-	13
96	4	-	1	4	2	11
97	4	4	1	5	-	14
98	7	1	6	8	1	23
99	4	2	1	8	3	18
100	9	1	6	11	4	31
101	3	2	4	8	1	18
102	3	3	2	13	2	23
103	5	-	7	6	-	18
104	3	-	9	5	-	17
105	4	1	4	4	2	15
106	7	-	9	6	1	23
107	7	3	5	9	-	24
108	1	2	8	11	-	22
109	3	3	9	14	3	32
110	2	4	11	7	-	24
111	3	-	3	4	1	11
112	2	2	5	3	-	12
113	1	-	1	2	-	4
114	-	-	-	2	1	3
115	-	-	-	-	-	-
116	1	-	-	1	-	2
117	-	-	-	-	-	-
118	-	-	-	-	-	-
119	-	-	-	-	-	-
120	-	-	-	-	-	-
121	-	-	-	-	-	-
122	-	-	-	-	-	-
123	-	-	-	-	-	-
124	-	-	1	-	-	1
Mean	101	99	100	100	100	
Estimated mean wt. (lbs.)	48	46	47	47	47	

Table 10.--Length frequencies of longline-caught skipjack measured during the mothership expeditions (East longitude)

Length (cm.)	April 14- June 10, 1951	June 11- Oct. 21, 1951
	138°-164°	155°-179°
47	1	1
48	0	-
49	0	2
50	0	-
51	4	1
52	4	3
53	14	2
54	25	3
55	34	11
56	22	13
57	37	22
58	22	16
59	11	23
60	6	26
61	10	17
62	4	20
63	5	14
64	5	8
65	2	8
66	1	4
67	1	3
68	-	6
69	-	2
70	-	4
71	-	3
72	-	1
73	-	-
74	-	-
75	-	3
76	-	2
77	-	1
78	-	1
79	-	3
80	-	-
81	-	1
82	-	1
Mean	57	61
Estimated mean weight (lbs.)	9	12

It is an attractive notion that the variations in catch rates associated with latitude are a reflection of variations in the circulation of the ocean in the vicinity of the Equator in the western Pacific. The attractiveness is enhanced by the knowledge that the major currents flow either east or west in that area (fig. 11), resulting in rapid changes in the environment on its north-south axis and little change along its east-west axis. This simple observation of the environment correlates rather well with the observation that within the mothership area there was little consistent change in abundance with longitude, and considerable change in abundance with latitude, with yellowfin most abundant near the Equator.

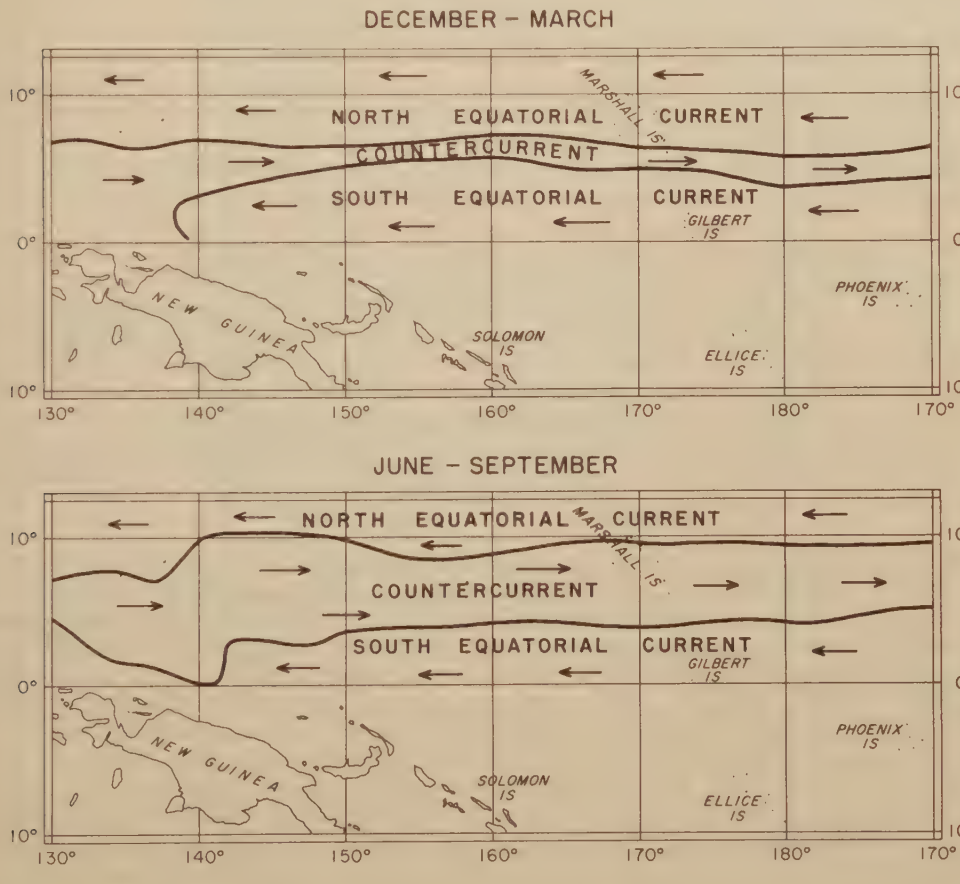

DECEMBER - MARCH
NORTH EQUATORIAL CURRENT
COUNTERCURRENT
SOUTH EQUATORIAL CURRENT
MARSHALL IS
GILBERT IS
PHOENIX IS
ELLICE IS
SOLOMON IS
NEW GUINEA
10°
0°
10°
130°
140°
150°
160°
170°
180°
170°
JUNE - SEPTEMBER
NORTH EQUATORIAL CURRENT
COUNTERCURRENT
SOUTH EQUATORIAL CURRENT
MARSHALL IS
GILBERT IS
PHOENIX IS
ELLICE IS
SOLOMON IS
NEW GUINEA
10°
0°
10°
130°
140°
150°
160°
170°
180°
170°

Figure 11.--Location of the major currents in the mothership area of operation (after Schott 1935).

Farther east, in the central Pacific, a zone in the vicinity of the Equator, extending to a few degrees north, is enriched by wind-induced upwelling (Cromwell 1954). The most important winds in this area are those from the southeast quadrant, which create upwelling and displace the upwelled water to the northward. This upwelling results in an increased supply of zooplankton (King and Demond 1953), and this basic food appears to be related to the relatively dense population of yellowfin found near the Equator (Murphy and Shomura 1953a). The location of tuna in the western Pacific is very similar and it seems possible that similar ecological factors, influencing the distribution of tuna in the central Pacific, are operating farther to the west.

However, in the western Pacific the relative absence of vigorous winds, particularly those from the southeast quadrant (table 11), would seem to preclude the same intensity of both the upwelling and the northern displacement of the richer water described by Cromwell (1954); at best a system activated by these winds would be weak or sporadic. The general weakness of the winds in the western Pacific is indicated in table 11 by the size of the index numbers, which are measures of the relative constancy and force of winds from the southeast quadrant. Pilot chart indices derived for the central Pacific (140°W. long.) were in general 2 to 10 times those from the western Pacific during the 2 years of mothership records, indicating that the forces activating the circulation are of a lesser order of magnitude in the western Pacific.

An examination of the seawater temperature sections in figures 12-15 reveals a lack of evidence of upwelling in any of the sections; that is, the cooler deeper isotherms do not reach the surface near the Equator as is typical of the temperature sections from the central equatorial Pacific (Cromwell 1951, 1954; Yoshida et al. 1953). While it is true that the 3 sections shown in figure 12 are pre-war and those in figure 14 adapted from Robinson were from 1946 data, the feature of the lack of doming of the isotherms at the Equator is common to all the sections including those taken by the Japanese research vessel Tenyo Maru in August and September 1951 in the region of the mothership operations (fig. 13). These two sections are the most pertinent as they were taken concurrently with the mothership fishing at a time when yellowfin showed a definite peak of abundance just north of the Equator (fig. 7).

Accompanying the general lack of evidence for upwelling in the western Pacific, as contrasted with the central Pacific, are differences in the catch rates of yellowfin tuna even though the pattern of latitudinal distribution is similar. In the central Pacific, with good evidence of strong upwelling, catches averaging around 6 per 100 hooks have been experienced to the north of the Equator (Murphy and Shomura 1953a, b, and unpublished data). In the apparent absence of upwelling in the western Pacific, catches were in the order of 2 to 3 fish per 100 hooks. However, the fact that the relative latitudinal distribution of yellowfin in the western Pacific, where evidences of upwelling appear to be absent at least part of the time, is similar to that in the central Pacific, where upwelling is definitely evident most of the time, suggests a possible conflict with the upwelling-plankton-forage-tuna cycle proposed for the central Pacific (Murphy and Shomura 1953). This conflict may not be real, however, because there may be upwelling in the western Pacific during some months and during some years as indicated by Mao and Yoshida (1953), and the distribution pattern of the yellowfin found there may reflect an integration of average conditions rather than the momentary ecological situation measured by hydrographical or biological means. It may also be that the peculiar ecological conditions in the immediate vicinity of the Equator favor yellowfin at the expense of other fishes occupying the same position in the food chain, with or without upwelling. Even slight and occasional upwelling superimposed on this background might have permitted the expansion of the yellowfin population.

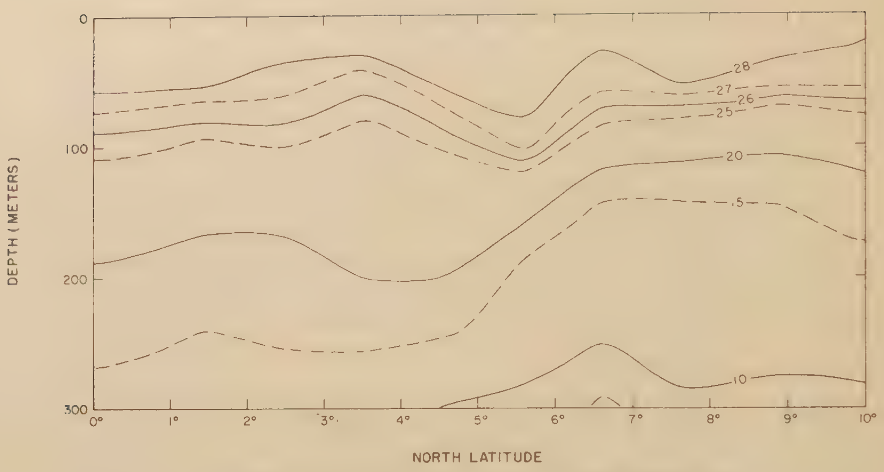
Superimposed on the rather regular occurrence of a peak in yellowfin abundance near the Equator are the variations in abundance with time. Analysis of the mothership catch records, while only for two years, suggests that there may be regularly occurring cycles of abundance within a year.

Table 11.--A comparison of the indices of the amount and strength of southeast winds during the Japanese mothership expeditions[1] with those derived from average winds from 1951 U. S. Pilot Charts. The block used is the 0°-5°N. latitude. The longitude refers to the western boundary of a block 5° wide. Only those blocks with 10 or more observations are included

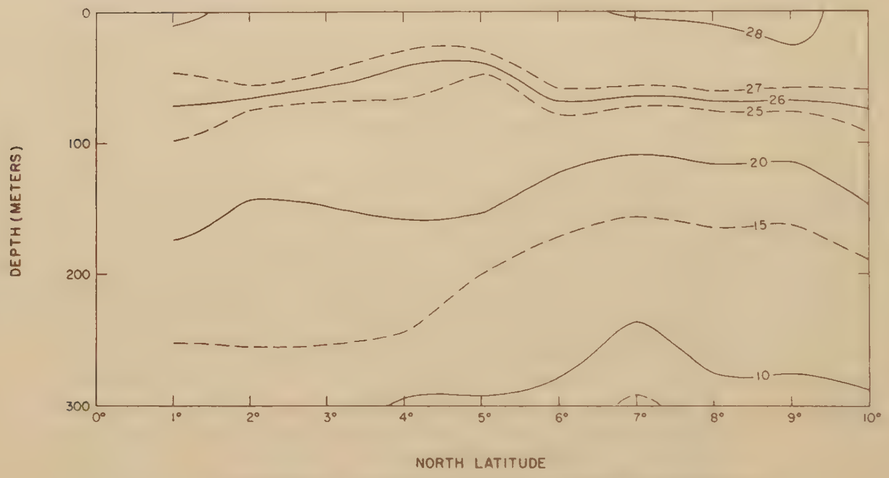
Date	Data from Japanese Mothership Expeditions							Data from U. S. Pilot Charts	
	East longitude						Mean monthly indices	Average monthly winds, mothership[2] area	Average monthly winds for 140° W. L.
	140°	145°	150°	155°	160°	165°			
June 1950	131	98	--	--	--	--	115	93	207
July 1950	88	80	119	114	136	--	107	108	316
Aug. 1950	--	--	--	114	111	151	125	83	228
Sept. 1950	--	--	--	--	178	174	176	169	252
April 1951	47	34	40	22	--	--	36	60	144
May 1951	--	--	26	36	21	--	28	68	144
June 1951	--	--	40	46	11	--	32	131	207
July 1951	--	--	--	--	66	46	56	176	316
Aug. 1951	--	--	28	38	24	--	30	72	228
Sept. 1951	--	--	--	6	38	48	30	147	252
Oct. 1951	--	--	--	--	--	21	21	96	288

[1] These data were taken from catcher vessel logs. Winds from the SE quadrant were summarized by multiplying the percent of the time the wind blew from that quadrant by the average Beaufort Force. One-half of the border winds, E and S, were credited to the SE quadrant. This yields a rough relative index, though it is not linear, and furthermore, winds of various strengths do not move water in direct proportion to their velocity. Nevertheless the index provides a comparison between areas and time periods. Meteorological and hydrographic observations taken during the mothership expeditions are summarized by year, month, and 5° square blocks in appendix table 13.

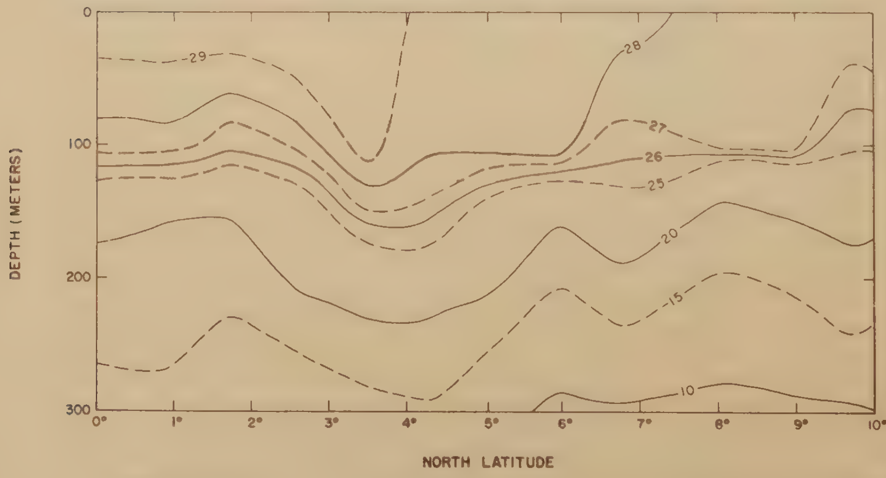
[2] Data taken from 1951 U. S. Pilot Charts for the same blocks as those from the mothership logs.



TEMPERATURE SECTION AT 138° EAST LONGITUDE JANUARY 1936

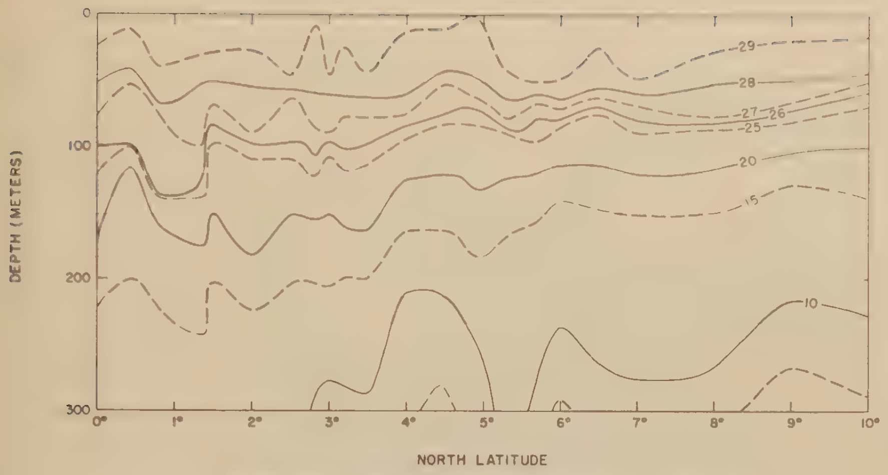


TEMPERATURE SECTION AT 136° EAST LONGITUDE FEBRUARY 1935

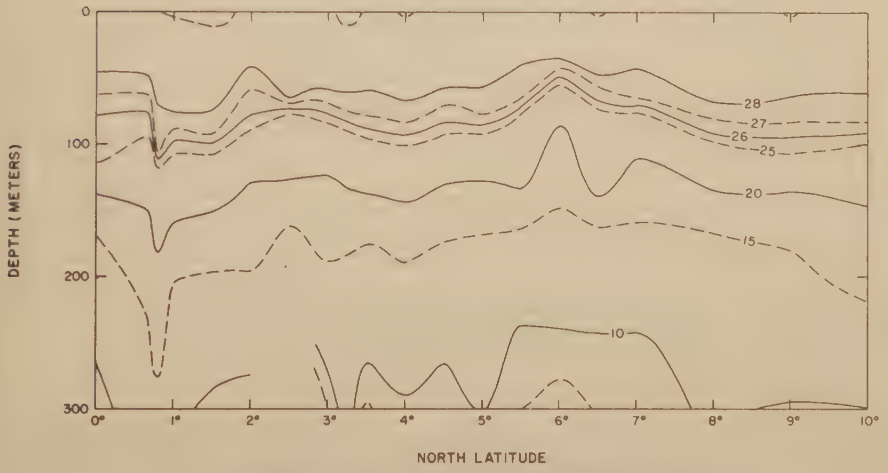


TEMPERATURE SECTION AT 147° (SOUTH END) – 150° (NORTH END) EAST LONGITUDE FEBRUARY 1936

Figure 12.--Three temperature sections based on Japanese hydrographic stations. Data furnished by U. S. Navy Hydrographic Office cruise reference numbers 90015 and 90019. Isotherms are in centigrade.



TEMPERATURE SECTION AT 160° EAST LONGITUDE SEPTEMBER 1951



TEMPERATURE SECTION AT 150° EAST LONGITUDE AUGUST 1951

Figure 13.--Two temperature cross sections based on hydrographic stations taken by the Japanese research vessel Tenyo Maru. Bottle depths were estimated from wire angles and so the location of the deeper isotherms must be accepted with caution. Isotherms are in centigrade.

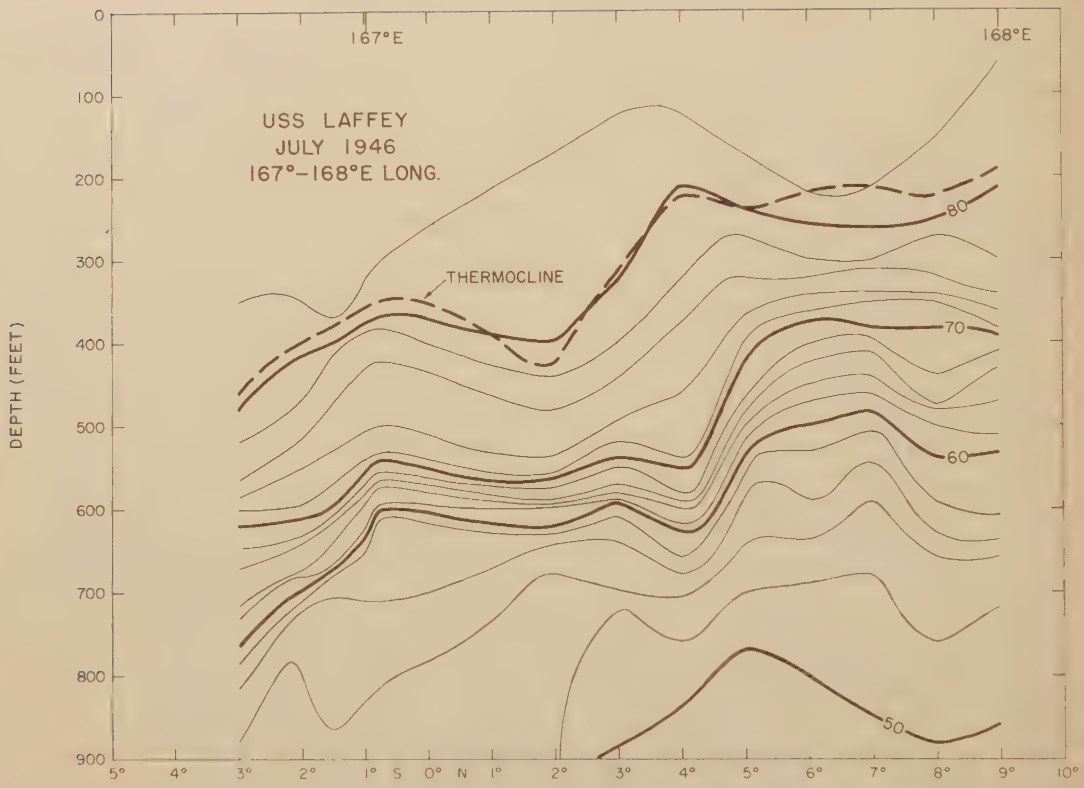


Figure 14.--Vertical temperature section at 167°-168°E. longitude. Adapted from Robinson (1952). Isotherms are in Fahrenheit.

There is also some indication from the pre- and post-war fishing in the mothership area of long term cyclic or epochal fluctuations in abundance. Nakamura (1943) reported commercial catches (tunas and spearfishes) of 6.05 per 100 hooks between 0° and 5°N. latitude and 1.70 north of 10°N. during pre-war years. If these data are comparable with the post-war mothership data, the indications are that the location of greatest abundance was the same then as now, but that the pre-war level of abundance was higher. In addition to the general figures on the commercial catch, a considerable amount of exploratory fishing was carried out by the Japanese in the area. Watanabe (1940) reported 3.4 yellowfin tuna per 100 hooks at 1° 20'N., 172° 30'E. on May 16, 1940. Uehara (1941) reported catches of 10 to 14 tunas and spearfishes per 100 hooks for four stations from 0° 11' to 1° 11' north of the Equator between 131° and 134°E. longitude during May 1941. Ikebe (1942) reported slightly higher catches in this same general longitude but south of the Equator during July 1941. Ikebe (1941) reported on five stations between the Equator and 5°N. lying between 146° and 169°E. longitude with catches of yellowfin tuna of 6, 5, 23, 19, and 15 per 100 hooks.

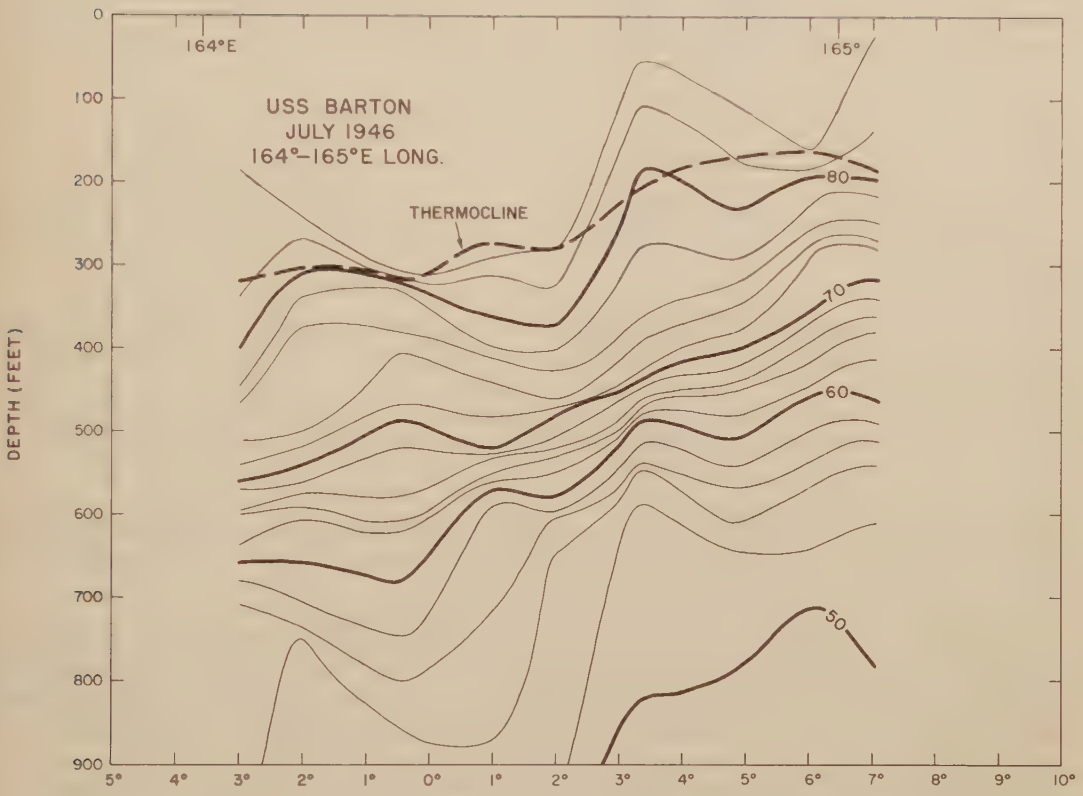


Figure 15.--Vertical temperature section at 164°-165°E. longitude. Adapted from Robinson (1952). Isotherms are in Fahrenheit.

Even if the difference between pre-war survey catch rates and post-war commercial fishing catch rates is not a reflection of a change in abundance, there remains a considerable difference between the catches of commercial operations in 1940-41 and 1950-51 (roughly 6 fish per 100 hooks versus 3 fish per 100 hooks). The cause of this apparent decline in abundance is presently obscure. It should, however, be pointed out that the decline occurred during a period (World War II) characterized by little or no fishing for tuna in the western Pacific, indicating that either there were natural changes in the population level or there were changes in the environment in the mothership area that reduced its suitability for yellowfin tuna.

SUMMARY

1. Nine Japanese mothership expeditions fished for tuna in the western equatorial Pacific Ocean between June 1950 and October 1951. Fishing was carried on from 135° to 180°W. longitude and from 1° to 10°N. latitude.

2. Each catcher vessel maintained a daily log of its fishing activity.

3. The two baits used, sardines and sauries, were about equal in terms of catch.

4. With minor exceptions the vessels participating in the expeditions were about equal in efficiency, indicating the catch rates could be used as indexes of abundance without adjustment.

5. In the region just north of the Equator (1°- 5°N.) the abundance of yellowfin tuna, bigeye tuna, and black marlin does not change appreciably between 135° and 170°E. longitude.

6. In the region just north of the Equator there were some evidences of a mid-northern summer and a mid-northern winter peak in abundance of yellowfin and bigeye tuna. Black marlin did not show any such peaks.

7. In general, within the range of latitudes sampled, yellowfin tuna were most abundant betwee the Equator and 4°N. latitude. Abundance of bigeye tuna appeared to increase north of 4°N. latitude, as did that of black marlin also.

8. The sizes of tunas caught indicate that the longline is sampling only a fraction of the population--the older, larger fish. Consideration of the size of longline skipjack leads to the conclusion that there is an ecological separation by size of yellowfin, bigeye, and albacore, with these species represented in the deeper waters mainly by large adults.

9. Wind velocities, particularly those from the southeast quadrant, were of a low order of magnitude when compared with those from the central Pacific.

10. The pattern of latitudinal distribution of yellowfin tuna in the western Pacific, where evidences of equatorial upwelling are lacking from the data at hand, is similar to the pattern in the central Pacific, where evidences of equatorial upwelling are present on all hydrographic sections examined. However, the absolute level of the population of yellowfin was higher in the central Pacific in 1951 than in the western Pacific in 1950-51.

11. Judging from pre-war published reports and post-war mothership data, tunas, in particular the yellowfin, were considerably more abundant just prior to World War II than during 1950-51 in the equatorial region of the western Pacific.

APPENDIX

Table 12. -- Catch per 100 hooks of yellowfin tuna by vessels and by months[1/]

Month	Year	Expedition	Vessel																					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
June	1950	1	2.06	2.71	2.85	2.77	3.03	1.59	3.15	2.16	2.44	3.04	2.88	2.09	2.02	2.08	1.71	3.11	3.16	2.72	2.63	2.91	-	-
July			1.96	2.00	2.26	2.48	2.63	1.71	2.05	2.17	1.70	1.97	2.59	2.11	2.14	3.66	1.70	2.77	1.57	1.95	2.80	2.07	-	-
Aug.			2.32	2.24	3.53	2.38	2.68	2.28	2.11	1.82	2.25	2.86	2.36	1.50	2.68	3.05	2.04	1.93	2.06	2.21	2.53	2.15	-	-
July	1950	2	1.83	2.33	2.69	2.57	2.84	2.48	3.47	2.07	2.48	1.97	3.87	1.97	-	-	-	-	-	-	-	-	-	-
Aug.			2.06	1.69	1.80	2.37	1.76	3.33	3.07	2.01	2.48	2.30	3.72	1.40	-	-	-	-	-	-	-	-	-	-
Sept.			3.08	2.74	2.94	2.30	3.86	2.45	2.75	2.09	2.21	3.56	3.17	2.77	-	-	-	-	-	-	-	-	-	-
April	1951	5	2.72	1.99	3.17	1.21	2.00	1.65	2.05	2.59	1.54	1.98	1.41	2.23	2.18	-	-	-	-	-	-	-	-	-
May			2.66	1.92	2.19	1.51	2.47	1.70	2.17	2.05	1.34	2.67	1.52	2.15	2.21	-	-	-	-	-	-	-	-	-
June			3.31	2.34	2.82	2.50	3.07	2.34	2.46	2.53	1.49	4.11	2.28	2.52	2.92	-	-	-	-	-	-	-	-	-
June	1951	7	3.29	3.21	1.36	1.87	3.78	4.75	3.40	1.82	4.26	1.93	3.50	3.40	3.68	3.53	2.30	2.66	4.01	2.68	3.45	2.57	3.16	2.49
July			2.26	2.27	3.00	1.71	2.54	2.27	2.24	1.43	4.31	1.46	3.08	2.60	2.31	2.28	2.21	2.53	2.43	2.49	2.78	2.09	2.13	2.62
Aug.			1.59	1.26	1.73	0.79	2.05	0.73	0.96	0.54	0.97	1.02	0.94	0.50	1.35	0.57	0.96	1.28	0.65	1.06	0.62	1.38	0.75	1.47
Aug.	1951	8	1.71	1.66	1.96	2.32	2.42	2.91	1.91	2.50	2.29	2.73	2.56	2.42	2.65	2.28	3.27	1.79	2.16	1.83	2.25	2.69	2.00	-
Sept.			1.56	1.13	1.35	2.16	1.77	1.38	1.75	2.11	2.31	2.08	2.26	2.49	2.59	1.66	1.68	2.37	2.20	1.29	1.74	1.53	1.36	-
Oct.			0.73	0.60	0.47	0.89	0.86	0.11	0.55	0.47	0.25	1.31	0.18	0.45	0.28	1.61	0.13	0.15	0.31	0.11	0.18	0.37	0.18	-

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[1/] Vessels which did not fish all of the three months are omitted from table.

Table 13.--Wind and surface temperature data from noon reports of catcher vessels, 1950-51. The data are grouped in 5-degree blocks identified by the SW coordinates. The upper figure is the percent of observations, the lower the average force (all longitudes are east and all latitudes north)

Date	Block	Mean temp.	No. obs.	Direction																
				N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
June 1950	0°-145°	29.1	68	-	1.5	2.9	7.4	20.6	13.2	22.1	10.3	5.9	1.5	1.5	-	-	-	-	-	13.2
				-	1.0	2.0	2.2	1.9	1.4	1.8	1.9	1.8	2.0	2.0	-	-	-	-	-	0.0
	5°-145°	29.0	9	-	-	11.1	11.1	22.2	22.2	22.2	11.1	-	-	-	-	-	-	-	-	-
				-	-	1.0	1.0	2.0	2.0	2.0	2.0	-	-	-	-	-	-	-	-	-
	5°-140°	29.2	11	-	-	-	9.1	27.3	18.2	45.4	-	-	-	-	-	-	-	-	-	-
				-	-	-	1.0	1.0	2.0	2.0	-	-	-	-	-	-	-	-	-	-
	0°-140°	29.0	104	-	-	4.8	1.9	18.3	11.5	34.6	3.8	8.6	4.8	4.8	-	1.9	-	1.0	-	3.8
				-	-	1.2	2.0	1.4	1.7	1.5	2.0	1.4	2.0	1.6	-	2.0	-	1.0	-	0.0
July 1950	0°-145°	29.4	137	1.5	2.9	5.8	5.8	19.7	3.7	27.7	5.8	5.8	-	2.2	-	1.5	-	1.5	-	16.0
				1.0	1.0	1.4	1.4	1.3	2.4	1.9	1.4	1.0	-	1.0	-	1.5	-	1.0	-	0.0
	5°-145°	29.3	25	-	4.0	8.0	4.0	28.0	8.0	28.0	4.0	-	4.0	-	-	-	-	-	-	12.0
				-	1.0	1.5	2.0	1.7	2.0	1.6	1.0	-	1.0	-	-	-	-	-	-	0.0
	0°-140°	29.3	18	-	-	11.1	-	22.2	22.2	33.3	-	5.6	-	5.6	-	-	-	-	-	-
				-	-	1.5	-	1.2	2.0	1.2	-	1.0	-	1.0	-	-	-	-	-	-
	0°-150°	29.2	239	1.3	0.8	6.7	5.9	13.0	16.7	28.9	7.1	4.6	0.4	1.3	-	0.4	0.4	1.3	0.4	10.9
				1.3	1.5	1.6	1.6	1.8	1.7	1.6	1.5	1.5	1.0	1.3	-	1.0	1.0	1.3	1.0	0.0
	5°-150°	29.2	60	-	3.3	5.0	8.3	21.7	6.7	38.3	3.3	1.7	-	3.3	-	-	-	5.0	-	3.3
				-	1.0	1.3	2.0	1.5	2.2	1.5	2.5	2.0	-	1.5	-	-	-	1.3	-	0.0
	0°-155°	29.3	106	2.8	2.8	4.7	5.7	17.0	20.8	24.5	4.7	2.8	-	0.9	-	-	-	2.8	2.8	7.5
				1.3	1.7	1.4	1.3	1.7	1.9	1.8	1.2	1.7	-	1.0	-	-	-	2.0	1.3	0.0
	5°-155°	29.2	11	18.2	-	-	-	27.3	-	36.4	9.1	9.1	-	-	-	-	-	-	-	-
				1.0	-	-	-	1.0	-	1.0	2.0	1.0	-	-	-	-	-	-	-	-
	0°-160°	28.9	59	-	-	13.6	8.5	27.1	18.6	23.7	1.7	-	-	-	-	1.7	-	-	1.7	3.4
				-	-	1.6	1.8	1.6	2.5	1.7	2.0	-	-	-	-	1.0	-	-	1.0	0.0
	5°-160°	29.0	14	7.1	-	14.3	-	14.3	21.4	-	14.3	-	-	-	-	-	7.1	-	-	21.4
				1.0	-	1.5	-	1.5	2.0	-	2.5	-	-	-	-	-	1.0	-	-	0.0
Aug. 1950	0°-150°	29.4	7	14.3	-	14.3	14.3	-	28.6	28.6	-	-	-	-	-	-	-	-	-	-
				2.0	-	2.0	3.0	-	1.5	2.5	-	-	-	-	-	-	-	-	-	-
	0°-155°	29.0	510	0.8	1.8	8.6	7.6	22.0	20.6	22.7	2.2	4.1	0.6	1.8	0.8	0.6	0.2	0.8	-	4.9
				1.0	2.0	1.9	1.9	1.9	2.3	1.9	1.7	2.0	2.0	1.6	1.8	2.0	1.0	1.5	-	0.0
	5°-55°	29.1	50	8.0	2.0	14.0	10.0	16.0	6.0	10.0	4.0	10.0	2.0	4.0	2.0	2.0	-	4.0	-	6.0
				1.2	2.0	1.7	2.0	1.9	2.3	1.6	3.0	1.8	2.0	2.5	3.0	1.0	-	1.5	-	0.0
	0°-60°	29.0	104	2.9	1.9	12.5	10.6	17.3	16.3	21.2	9.6	4.8	1.0	-	-	-	-	-	-	1.9
				1.0	2.5	2.5	2.1	1.7	1.7	2.1	1.6	3.0	4.0	-	-	-	-	-	-	0.0

Table 13.--Wind and surface temperature data from noon reports of catcher vessels, 1950-51. The data are grouped in 5-degree blocks identified by the SW coordinates. The upper figure is the percent of observations, the lower the average force (all longitudes are east and all latitudes north) (cont'd)

Date	Block	Mean temp.	No. obs.	Direction																
				N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
Aug. 1950 (Con.)	5°-60°	28.9	6	-	16.7	-	16.7	16.7	-	33.3	16.7	-	-	-	-	-	-	-	-	-
				-	2.0	-	1.0	1.0	-	1.5	1.0	-	-	-	-	-	-	-	-	-
	0°-65°	28.8	175	0.6	2.3	6.3	13.7	30.3	16.0	23.4	6.3	-	-	-	-	0.6	-	-	-	0.6
				2.0	2.5	2.1	2.3	2.5	2.5	2.2	1.7	-	-	-	-	2.0	-	-	-	0.0
	5°-65°	28.7	30	-	-	6.7	16.7	53.3	10.0	10.0	-	3.3	-	-	-	-	-	-	-	-
				-	-	2.5	2.2	2.1	2.0	1.7	-	2.0	-	-	-	-	-	-	-	-
Sept. 1950	5°-50°	29.0	22.	-	-	-	-	22.7	9.1	40.9	13.6	4.5	-	4.5	-	-	-	4.5	-	-
				-	-	-	-	1.8	2.5	1.4	1.3	1.0	-	2.0	-	-	-	2.0	-	-
	5°-55°	29.0	35	-	-	5.7	-	8.6	20.0	40.0	8.6	8.6	-	-	-	-	-	2.9	-	5.7
				-	-	1.5	-	1.3	1.3	1.9	2.0	1.0	-	-	-	-	-	1.0	-	0.0
	0°-60°	28.2	53	-	-	7.5	1.9	15.1	28.3	22.6	11.3	7.5	1.9	-	-	-	-	1.9	-	1.9
				-	-	2.8	1.0	1.6	2.7	2.2	2.7	2.2	2.0	-	-	-	-	2.0	-	0.0
	5°-60°	28.8	15	-	-	13.3	20.0	20.0	6.7	36.7	6.7	6.7	-	-	-	-	-	-	-	-
				-	-	1.0	2.0	2.7	3.0	1.5	3.0	4.0	-	-	-	-	-	-	-	-
	0°-65°	28.0	172	-	-	5.2	7.0	27.9	30.2	27.9	1.2	0.6	-	-	-	-	-	-	-	-
				-	-	2.9	2.0	2.2	2.2	2.6	2.0	1.0	-	-	-	-	-	-	-	-
Dec. 1950	0°-40°	28.8	4	50.0	-	25.0	25.0	-	-	-	-	-	-	-	-	-	-	-	-	-
				1.0	-	2.0	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-
	0°-35°	29.1	82	18.3	8.5	11.0	-	-	-	2.4	-	2.4	1.2	3.7	4.9	9.8	7.3	20.7	7.3	2.4
				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jan. 1951	25°-40°	-	5	-	-	40.0	-	40.0	20.0	-	-	-	-	-	-	-	-	-	-	-
				-	-	4.5	-	4.5	2.0	-	-	-	-	-	-	-	-	-	-	-
Feb. 1951	0°-55°	29.1	165	0.6	0.6	11.5	27.9	42.4	9.7	4.2	1.2	0.6	0.6	0.6	-	-	-	-	-	-
				2.0	3.0	2.2	2.0	1.9	1.6	1.4	2.5	1.0	2.0	1.0	-	-	-	-	-	-
	5°-55°	29.1	15	-	20.0	46.7	26.7	6.7	-	-	-	-	-	-	-	-	-	-	-	-
				-	3.3	3.0	3.5	2.0	-	-	-	-	-	-	-	-	-	-	-	-
	0°-60°	29.0	40	2.5	5.0	10.0	22.5	25.0	27.5	7.5	-	-	-	-	-	-	-	-	-	-
				2.0	1.5	2.0	1.9	1.5	1.7	1.7	-	-	-	-	-	-	-	-	-	-
Mar. 1951	0°-40°	29.4	28	25.0	14.3	7.1	7.1	-	-	-	-	3.6	3.6	3.6	-	-	10.7	14.3	10.7	-
				1.6	1.5	1.0	1.0	-	-	-	-	1.0	1.0	3.0	-	-	2.0	1.8	1.7	-
	0°-35°	29.7	9	44.4	55.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				1.5	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13.--Wind and surface temperature data from noon reports of catcher vessels, 1950-51. The data are grouped in 5-degree blocks identified by the SW coordinates. The upper figure is the percent of observations, the lower the average force (all longitudes are east and all latitudes north) (cont'd)

Date	Block	Mean temp.	No. obs.	Direction																
				N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
April 1951	0°-45°	29.1	105	5.7	14.3	21.9	8.6	21.0	1.9	5.7	2.9	7.6	3.8	2.9	-	1.0	-	1.0	-	1.9
				2.2	2.1	2.3	2.2	1.9	3.0	2.0	2.0	3.1	3.5	3.0	-	3.0	-	2.0	-	0.0
	5°-45°	28.6	15	-	13.3	46.7	20.0	6.6	-	-	6.7	-	-	-	-	-	6.7	-	-	-
				-	2.0	3.3	3.3	1.0	-	-	2.0	-	-	-	-	-	2.0	-	-	-
	0°-40°	29.5	13	-	15.4	15.4	23.1	30.8	7.7	-	-	-	-	-	-	-	-	7.7	-	-
				-	3.0	1.5	2.7	1.8	2.0	-	-	-	-	-	-	-	-	1.0	-	-
	0°-50°	29.0	155	11.6	4.5	11.6	6.5	5.8	3.2	11.0	2.6	1.3	1.9	12.3	5.2	10.3	3.2	7.1	1.9	-
				1.3	1.7	1.3	1.7	2.2	2.2	1.9	1.8	2.0	2.3	2.1	2.5	2.1	3.2	2.2	1.3	-
	0°-55°	29.0	71	2.8	2.8	22.5	4.2	12.7	-	7.0	1.4	7.0	4.2	9.9	5.6	8.5	1.4	8.5	1.4	-
				1.5	1.0	1.4	2.3	1.4	-	1.6	1.0	1.2	3.3	2.7	3.2	2.2	4.0	2.0	4.0	-
May 1951	0°-50°	29.0	40	12.5	-	5.0	5.0	5.0	2.5	10.0	-	-	2.5	2.5	-	2.5	2.5	32.5	12.5	5.0
				3.4	-	1.0	1.5	1.5	1.0	1.5	-	-	2.0	1.0	-	4.0	3.0	3.1	3.8	0.0
	0°-55°	28.6	176	2.3	3.4	23.3	10.2	13.6	2.3	5.1	1.1	4.5	2.3	9.7	2.8	6.2	3.4	5.1	2.8	1.7
				2.8	1.8	1.7	1.9	1.6	1.8	1.0	3.0	2.0	2.8	2.6	3.8	2.6	3.3	3.6	4.2	0.0
	5°-55°	28.5	36	2.8	-	25.0	33.3	33.3	5.6	-	-	-	-	-	-	-	-	-	-	-
				1.0	-	2.1	1.7	1.9	3.0	-	-	-	-	-	-	-	-	-	-	-
	0°-60°	28.8	209	4.8	1.9	23.0	11.5	9.1	1.0	3.8	2.9	4.8	6.2	15.3	9.6	2.9	-	1.4	1.0	1.0
				1.3	1.5	2.1	2.5	1.9	1.5	1.4	2.2	1.4	1.5	2.1	2.1	1.3	-	1.0	1.5	0.0
	5°-60°	28.4	27	-	7.4	33.3	48.1	3.7	-	3.7	-	-	-	-	-	-	-	-	3.7	-
				-	2.5	3.3	2.7	3.0	-	3.0	-	-	-	-	-	-	-	-	1.0	-
June 1951	0°-50°	29.3	102	2.9	2.9	24.5	15.7	21.6	4.9	3.9	1.0	-	-	8.8	1.0	1.0	1.0	7.8	2.0	1.0
				2.0	1.7	1.7	2.0	2.1	1.4	2.5	1.0	-	-	1.9	2.0	1.0	1.0	1.6	1.0	-
	0°-55°	29.0	183	3.8	3.8	17.5	13.1	16.4	2.7	9.3	2.7	6.0	3.8	6.0	1.6	2.7	1.6	6.6	1.6	0.6
				1.4	2.1	1.8	1.7	1.9	1.8	1.7	2.0	2.5	2.9	1.9	2.0	1.8	2.7	1.5	1.3	0.0
	5°-55°	28.5	39	2.6	5.1	23.1	15.4	12.8	2.6	15.4	-	-	5.1	2.6	-	2.6	2.6	10.3	-	-
				1.0	2.0	1.4	2.2	1.2	3.0	1.7	-	-	2.0	2.0	-	2.0	2.0	1.2	-	-
	0°-60°	28.7	82	6.1	7.3	26.8	3.7	4.9	-	4.9	1.2	8.5	7.3	7.3	1.2	6.1	1.2	9.8	2.4	1.2
				1.4	1.3	1.5	1.0	1.8	-	1.2	1.0	1.6	1.7	1.2	1.0	1.6	2.0	1.4	1.5	0.0
	5°-60°	28.8	8	-	12.5	25.0	12.5	12.5	12.5	-	-	-	-	12.5	-	12.5	-	-	-	-
				-	2.0	2.5	2.0	2.0	2.0	-	-	-	-	2.0	-	1.0	-	-	-	-
July 1951	0°-60°	28.9	147	0.7	2.7	21.8	13.6	16.3	14.3	12.9	4.8	4.8	0.7	1.4	-	1.4	2.0	2.0	-	0.7
				1.0	1.8	1.4	1.6	1.8	1.4	1.8	1.9	1.0	1.0	1.5	-	1.5	1.0	2.0	-	0.0
	5°-60°	28.8	25	-	12.0	28.0	16.0	20.0	4.0	8.0	4.0	-	-	-	4.0	-	-	4.0	-	-
				-	3.3	2.0	2.0	2.0	2.0	1.5	1.0	-	-	-	2.0	-	-	2.0	-	-

Table 13.--Wind and surface temperature data from noon reports of catcher vessels, 1950-51. The data are grouped in 5-degree blocks identified by the SW coordinates. The upper figure is the percent of observations, the lower the average force (all longitudes are east and all latitudes north) (cont'd)

Date	Block	Mean temp.	No. obs.	Direction																
				N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
July 1951 (con.)	0°-65°	28.9	235	4.3	3.4	24.7	17.4	18.3	4.3	6.8	2.1	4.3	2.6	3.4	0.4	0.9	0.9	1.7	0.4	4.3
				1.2	2.2	2.2	2.4	1.9	1.6	1.7	2.6	1.1	1.7	1.2	3.0	2.0	2.0	1.8	1.0	0.0
	5°-65°	28.7	90	5.6	6.7	37.8	17.8	12.2	3.3	6.7	2.2	2.2	2.2	-	-	1.1	-	1.1	-	1.1
				2.0	2.2	1.9	2.1	1.5	2.3	1.7	1.5	1.5	1.5	-	-	2.0	-	1.0	-	0.0
	5°-70°	28.6	83	2.4	4.8	41.0	10.8	14.5	3.6	16.9	1.2	1.2	-	-	-	-	2.4	-	-	1.2
				1.0	1.2	1.8	1.9	1.6	3.0	1.5	2.0	2.0	-	-	-	-	2.5	-	-	0.0
Aug. 1951	0°-50°	28.9	25	4.2	-	25.0	-	16.7	4.2	8.3	-	8.3	-	-	4.2	4.2	-	12.5	-	12.5
				1.0	-	1.2	-	1.0	3.0	1.0	-	2.0	-	-	3.0	3.0	-	1.3	-	0.0
	0°-55°	29.0	245	7.3	1.6	4.9	0.8	4.5	4.5	9.8	3.7	8.2	5.3	8.2	3.7	13.5	3.3	10.6	3.7	6.5
				1.7	1.8	1.1	1.5	1.5	1.2	1.7	2.4	2.2	2.5	2.0	2.1	1.9	1.5	1.7	1.9	0.0
	5°-55°	29.2	14	-	-	14.3	-	7.1	-	7.1	-	14.3	-	14.3	-	7.1	7.1	14.3	-	14.3
				-	-	1.0	-	1.0	-	1.0	-	1.5	-	2.0	-	1.0	2.0	2.0	-	0.0
	0°-60°	29.1	42	9.5	-	-	-	9.5	4.8	2.4	4.8	4.8	-	11.9	4.8	28.6	4.8	4.8	4.8	4.8
				1.0	-	-	-	1.0	1.0	2.0	2.0	1.0	-	1.6	2.5	2.4	1.0	2.0	1.0	0.0
	5°-60°	29.2	12	-	8.3	16.7	8.3	25.0	-	16.7	-	-	-	-	8.3	-	-	-	16.7	-
				-	2.0	2.0	2.0	2.0	-	1.0	-	-	-	-	1.0	-	-	-	2.0	-
	5°-65°	28.8	69	2.9	4.3	42.0	7.2	11.6	2.9	4.3	4.3	4.3	1.4	2.9	-	-	1.4	2.9	2.9	4.3
				1.0	2.0	1.7	1.2	1.8	2.5	1.0	1.3	2.7	2.0	2.0	-	-	1.0	2.0	1.5	0.0
	5°-70°	28.8	199	1.5	3.0	40.2	16.1	16.1	2.5	4.5	1.0	2.0	1.5	1.5	0.5	0.5	-	2.0	1.0	6.0
				2.0	1.2	1.8	1.8	1.3	2.4	1.3	1.0	2.0	1.7	1.7	2.0	1.0	-	1.2	1.0	0.0
	5°-70°	28.8	88	2.3	6.8	36.4	17.0	15.9	2.3	2.3	-	-	-	3.4	1.1	2.3	1.1	2.3	1.1	5.7
				3.5	3.0	2.2	2.2	2.4	2.0	2.5	-	-	-	1.7	2.0	1.0	2.0	1.5	1.0	0.0
	10°-70°	28.4	10	10.0	-	50.0	20.0	-	10.0	-	-	10.0	-	-	-	-	-	-	-	-
				1.0	-	2.0	1.5	-	1.0	-	-	2.0	-	-	-	-	-	-	-	-
	10°-75°	28.5	12	-	-	41.7	16.7	33.3	-	-	-	-	-	-	8.3	-	-	-	-	-
				-	-	2.0	2.5	2.8	-	-	-	-	-	-	1.0	-	-	-	-	-
Sept. 1951	0°-50°	29.5	6	16.7	-	-	-	-	16.7	-	-	16.7	16.7	-	-	16.7	-	-	-	16.7
				2.0	-	-	-	-	1.0	-	-	2.0	1.0	-	-	2.0	-	-	-	0.0
	0°-55°	30.0	118	12.7	0.8	0.8	1.7	0.8	-	2.5	3.4	10.2	3.4	14.4	2.5	9.3	1.7	10.2	4.2	21.2
				1.1	2.0	1.0	1.0	1.0	-	1.3	1.0	1.2	1.5	1.1	1.0	1.2	1.0	1.2	1.0	0.0
	5°-55°	29.6	9	11.1	-	-	-	-	-	-	-	-	-	44.4	-	-	-	11.1	11.1	22.2
				1.0	-	-	-	-	-	-	-	-	-	1.2	-	-	-	1.0	1.0	0.0
	20°-55°	29.3	4	25.0	-	-	-	-	-	-	-	-	-	-	25.0	50.0	-	-	-	-
				1.0	-	-	-	-	-	-	-	-	-	-	2.0	2.0	-	-	-	-
	0°-60°	30.0	202	7.4	2.5	9.9	3.0	17.3	2.0	7.9	0.5	2.5	1.0	6.9	1.5	6.9	3.0	4.5	3.5	19.8
				1.1	1.8	1.4	1.0	1.8	1.5	1.6	2.0	1.2	1.0	1.3	1.7	1.3	1.2	1.0	1.1	-

Table 13.--Wind and surface temperature data from noon reports of catcher vessels, 1950-51. The data are grouped in 5-degree blocks identified by the SW coordinates. The upper figure is the percent of observations, the lower the average force (all longitudes are east and all latitudes north)

Date	Block	Mean temp.	No. obs.	Direction																
				N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
Sept. 1951 (Con.)	5°-60°	30.4	6	16.7	16.7	-	33.3	-	-	-	-	16.7	-	-	-	-	-	-	-	16.7
				2.0	3.0	-	1.0	-	-	-	-	1.0	-	-	-	-	-	-	-	0.0
	0°-65°	29.7	129	5.4	3.1	14.0	14.0	20.9	7.0	8.5	2.3	2.3	0.8	-	0.8	2.3	2.3	5.4	1.6	9.3
				1.6	1.5	1.9	2.2	1.5	1.2	1.6	1.3	1.0	3.0	-	1.0	1.3	1.3	1.0	1.0	0.0
	5°-65°	29.7	53	1.9	9.4	20.8	7.5	26.4	3.8	5.7	3.8	3.8	1.9	1.9	-	3.8	-	-	-	9.4
				1.0	2.2	2.4	1.8	1.7	2.5	1.7	2.0	2.0	1.0	1.0	-	2.0	-	-	-	0.0
	5°-70°	29.5	42	2.4	-	31.0	19.0	28.6	7.1	7.1	-	2.4	-	-	-	-	-	2.4	-	-
				2.0	-	3.2	3.0	2.8	1.7	1.3	-	2.0	-	-	-	-	-	2.0	-	-
Oct. 1951	20°-50°	28.0	4	-	-	25.0	50.0	25.0	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	3.0	3.0	4.0	-	-	-	-	-	-	-	-	-	-	-	-
	0°-65°	29.5	45	11.1	13.3	6.7	4.4	15.6	2.2	11.1	-	4.4	6.7	13.3	-	-	-	6.7	-	4.4
				1.0	1.7	1.0	1.0	1.0	1.0	1.0	-	1.0	1.0	1.3	-	-	-	2.0	-	0.0
	25°-65°	28.3	4	-	-	25.0	25.0	50.0	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	4.0	3.0	2.0	-	-	-	-	-	-	-	-	-	-	-	-
	5°-70°	29.3	32	6.2	-	25.0	3.1	25.0	6.2	6.2	3.1	9.4	9.4	-	3.1	-	-	-	3.1	-
				1.5	-	1.4	3.0	2.2	3.0	2.5	2.0	2.0	2.3	-	1.0	-	-	-	1.0	-
	5°-75°	29.3	360	7.2	2.8	20.0	8.9	24.4	2.8	13.3	2.8	3.9	1.4	3.3	-	1.1	-	1.9	0.8	5.3
				1.7	1.7	1.7	2.1	1.7	1.6	1.9	2.2	1.9	1.4	1.8	-	1.0	-	1.1	1.7	0.0
	10°-75°	28.8	22	4.5	18.2	22.7	4.5	18.2	-	4.5	4.5	4.5	4.5	-	-	4.5	-	4.5	4.5	-
				2.0	2.2	2.2	3.0	2.5	-	2.0	3.0	1.0	4.0	-	-	1.0	-	2.0	1.0	-
	20°-75°	26.8	4	-	-	-	25.0	75.0	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	2.0	2.0	-	-	-	-	-	-	-	-	-	-	-	-
	25°-75°	24.9	4	-	-	50.0	50.0	-	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	2.5	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov. 1951	25°-60°	28.0	7	-	-	42.9	-	42.9	14.3	-	-	-	-	-	-	-	-	-	-	-
				-	-	2.7	-	2.3	2.0	-	-	-	-	-	-	-	-	-	-	-
	25°-65°	27.6	8	-	-	25.0	25.0	25.0	-	25.0	-	-	-	-	-	-	-	-	-	-
				-	-	3.0	2.0	2.5	-	4.5	-	-	-	-	-	-	-	-	-	-
	35°-65°	18.6	6	-	-	-	-	16.7	-	-	-	-	-	-	-	16.7	50.0	16.7	-	-
				-	-	-	-	3.0	-	-	-	-	-	-	-	3.0	4.0	4.0	-	-
	25°-75°	28.1	21	-	4.8	52.4	19.0	9.5	4.8	4.8	-	-	-	-	-	-	-	4.8	-	-
				-	3.0	2.1	3.2	3.5	1.0	2.0	-	-	-	-	-	-	-	1.0	-	-

Table 14.--Catches of the mothership expeditions for 1950. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees

Month	Lat. Long.	Boat days fished	Hooks[1/] fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
June	01°-40°	10	203	1.6	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.6
	01°-45°	13	271	2.5	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.8
	02°-40°	57	1,047	2.4	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.6
	02°-45°	18	307	2.4	0.3	0.0	0.0	0.6	0.0	0.0	0.0	0.7
	03°-40°	33	572	2.9	0.2	0.0	0.0	0.6	0.0	0.0	0.0	0.8
	03°-45°	10	202	2.6	0.3	0.0	0.0	0.6	0.0	0.0	0.0	0.9
	04°-40°	7	130	2.3	0.5	0.0	0.0	0.8	0.0	0.0	0.0	0.9
	04°-45°	30	579	3.1	0.3	0.0	0.0	0.6	0.0	0.0	0.0	0.6
	05°-40°	9	155	2.2	0.6	0.0	0.0	0.9	0.0	0.0	0.0	1.0
	05°-45°	9	181	3.2	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.7
	05°-50°	1	22	0.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.1
	06°-40°	3	52	2.2	0.5	0.0	0.0	0.9	0.0	0.1	0.1	0.7
July	01°-40°	12	240	2.2	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.8
	01°-45°	24	468	1.4	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.7
	01°-50°	65	1,298	2.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.4
	01°-55°	29	581	3.7	0.2	0.0	0.1	0.3	0.0	0.0	0.0	0.7
	01°-60°	10	207	2.7	0.4	0.0	0.0	0.5	0.0	0.0	0.0	0.9
	02°-40°	4	80	2.1	0.1	0.0	0.2	0.5	0.0	0.0	0.0	2.0
	02°-45°	28	542	1.6	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.7
	02°-50°	82	1,532	2.8	0.4	0.0	0.0	0.5	0.0	0.0	0.0	0.4
	03°-40°	3	43	2.0	0.6	0.0	0.0	0.6	0.0	0.1	0.0	2.3
	03°-45°	41	783	2.0	0.3	0.0	0.0	0.5	0.0	0.0	0.0	0.5
	03°-50°	37	706	1.9	0.3	0.0	0.0	0.5	0.0	0.0	0.0	0.5
	03°-55°	41	772	2.1	0.5	0.1	0.0	0.6	0.0	0.0	0.0	0.5
	03°-60°	9	180	2.8	0.4	0.0	0.0	0.5	0.0	0.0	0.0	0.3
	04°-45°	46	889	2.1	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.5
	04°-50°	54	990	1.9	0.3	0.0	0.0	0.6	0.0	0.0	0.0	0.6
	04°-55°	18	343	2.2	0.5	0.0	0.0	0.8	0.0	0.0	0.0	0.3
	04°-60°	32	614	2.8	0.6	0.0	0.0	0.9	0.1	0.0	0.0	0.4
	05°-40°	3	52	2.8	0.6	0.0	0.0	0.9	0.0	0.1	0.0	1.1
	05°-45°	21	413	2.2	0.5	0.0	0.0	0.7	0.0	0.0	0.0	0.7
	05°-50°	41	710	1.9	0.3	0.0	0.0	0.7	0.0	0.0	0.0	0.7
	05°-55°	9	161	2.6	0.5	0.1	0.1	1.0	0.0	0.0	0.0	0.7
	05°-60°	14	273	2.6	0.8	0.0	0.0	1.0	0.0	0.0	0.0	0.3
	06°-45°	3	60	1.7	0.1	0.0	0.0	0.9	0.0	0.0	0.0	0.4
	06°-50°	17	318	2.1	0.3	0.1	0.1	0.5	0.0	0.0	0.0	0.6
	06°-55°	3	55	2.3	0.5	0.0	0.0	1.0	0.0	0.0	0.0	0.3
	07°-45°	1	21	1.3	0.3	0.0	0.0	0.4	0.0	0.0	0.0	1.5
	07°-50°	2	37	1.4	0.1	0.1	0.0	0.5	0.0	0.0	0.0	0.8
Aug.	01°-40°	1	18	1.1	0.2	0.0	0.0	0.8	0.0	0.0	0.0	0.4
	01°-50°	3	53	1.4	0.3	0.0	0.0	0.4	0.1	0.0	0.0	0.6
	01°-55°	244	4,634	3.1	0.3	0.1	0.0	0.2	0.0	0.0	0.0	0.7
	01°-65°	16	325	3.6	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.6
	02°-40°	1	18	1.3	0.3	0.0	0.0	0.4	0.0	0.2	0.0	0.2

Table 14.--Catches of the mothership expeditions for 1950. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks[1] fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Shark
Aug. (con.)	02°-45°	1	18	2.8	0.3	0.0	0.0	0.6	0.0	0.0	0.0	0.8
	02°-50°	1	18	0.9	0.1	0.0	0.0	0.3	0.1	0.0	0.0	0.3
	02°-55°	67	1,222	2.0	0.2	0.0	0.1	0.5	0.0	0.0	0.0	0.5
	02°-60°	1	20	0.1	0.4	0.0	0.0	0.4	0.0	0.2	0.0	2.8
	02°-65°	9	177	1.7	0.2	0.0	0.0	0.8	0.0	0.0	0.0	0.3
	03°-45°	1	18	1.9	0.8	0.1	0.0	0.3	0.1	0.0	0.1	2.5
	03°-50°	1	18	3.5	0.1	0.1	0.0	0.3	0.0	0.0	0.0	0.1
	03°-55°	11	2,023	2.0	0.4	0.1	0.0	0.5	0.0	0.0	0.0	0.4
	03°-60°	30	619	2.5	0.3	0.0	0.0	0.8	0.0	0.0	0.0	0.3
	03°-65°	53	1,032	1.9	0.3	0.0	0.0	1.1	0.0	0.0	0.0	0.3
	04°-45°	1	18	0.3	0.1	0.1	0.0	0.5	0.0	0.0	0.0	0.7
	04°-50°	2	42	0.7	0.2	0.2	0.0	0.3	0.0	0.0	0.0	0.4
	04°-55°	90	1,760	2.1	0.3	0.1	0.0	0.6	0.0	0.0	0.0	0.4
	04°-60°	74	1,426	2.5	0.4	0.1	0.0	0.9	0.0	0.0	0.0	0.2
	04°-65°	99	1,845	2.4	0.4	0.1	0.0	1.2	0.0	0.0	0.0	0.2
	05°-50°	3	60	0.6	0.6	0.2	0.0	0.3	0.0	0.0	0.0	0.3
	05°-55°	40	776	1.9	0.4	0.1	0.0	0.7	0.0	0.0	0.0	0.5
	05°-60°	5	112	2.1	0.4	0.1	0.0	1.1	0.0	0.0	0.0	0.2
	05°-65°	24	452	1.7	0.5	0.1	0.0	0.8	0.0	0.0	0.0	0.3
	06°-55°	10	190	1.5	0.5	0.1	0.0	0.7	0.0	0.0	0.0	0.6
	06°-60°	1	21	0.9	0.5	0.1	0.0	0.7	0.0	0.0	0.0	0.1
	06°-65°	6	110	1.4	1.0	0.0	0.0	0.8	0.0	0.0	0.0	0.6
Sept.	01°-55°	1	22	1.4	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.4
	01°-60°	25	436	3.2	0.2	0.0	0.2	0.3	0.0	0.0	0.0	0.6
	01°-65°	69	1,326	3.4	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.7
	02°-60°	8	138	1.3	0.2	0.0	0.0	0.6	0.0	0.1	0.0	1.1
	02°-65°	79	1,486	3.1	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.6
	03°-50°	1	18	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	03°-60°	6	112	0.9	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.6
	03°-65°	15	260	2.1	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.3
	04°-55°	2	39	1.0	0.3	0.2	0.1	0.3	0.0	0.1	0.1	1.1
	04°-60°	14	242	1.1	0.2	0.0	0.0	0.8	0.0	0.1	0.0	0.3
	04°-65°	13	241	1.7	0.3	0.0	0.0	0.9	0.1	0.1	0.0	0.9
	05°-50°	1	18	5.8	0.6	0.0	1.2	0.8	0.1	0.2	0.2	1.8
	05°-55°	4	77	0.7	0.5	0.0	0.6	0.0	0.0	0.1	0.0	0.7
	05°-60°	12	217	1.6	0.4	0.0	0.0	0.7	0.0	0.0	0.0	0.3
	05°-65°	2	36	1.7	0.4	0.0	0.0	0.5	0.0	0.3	0.0	0.5
	06°-50°	8	146	1.5	0.4	0.0	0.1	1.0	0.0	0.1	0.0	1.0
	06°-55°	14	261	0.7	0.4	0.0	0.0	0.5	0.0	0.0	0.0	0.6
	06°-60°	1	21	0.6	0.4	0.0	0.0	1.0	0.0	0.0	0.0	0.3
	07°-50°	6	106	0.5	0.4	0.1	0.0	0.7	0.0	0.0	0.0	0.6
	07°-55°	11	204	0.8	0.5	0.1	0.0	0.8	0.0	0.0	0.0	0.1
	07°-60°	2	38	0.5	0.4	0.0	0.1	1.2	0.0	0.0	0.0	0.5
	08°-50°	7	126	1.0	0.4	0.0	0.0	1.0	0.0	0.0	0.0	0.5
	08°-55°	5	107	0.9	0.4	0.0	0.0	0.9	0.0	0.0	0.0	0.4

Table 14.--Catches of the mothership expeditions for 1950. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks 1/ fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
Sept. (con)	09°-55°	1	20	0.2	0.3	0.1	0.0	0.9	0.0	0.0	0.0	0.5
	10°-60°	2	42	0.3	0.2	0.0	0.0	1.5	0.0	0.0	0.0	0.3
Oct.	06°-60°	1	12	0.2	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0
	06°-75°	1	22	0.3	0.1	0.0	0.2	0.2	0.0	0.0	0.0	0.6
	10°-60°	1	21	0.1	0.3	0.0	0.0	0.9	0.0	0.0	0.0	0.5
Dec.	01°-35°	8	146	5.1	0.7	0.3	0.2	0.4	0.0	0.0	0.0	0.2
	02°-35°	60	1,082	3.6	0.4	0.1	0.1	0.5	0.0	0.0	0.0	0.2
	02°-40°	1	18	4.5	0.2	0.0	0.1	0.0	0.0	0.1	0.0	0.0
	03°-30°	1	12	3.1	0.2	2.2	0.0	0.1	0.0	0.1	0.1	0.7
	03°-35°	15	248	3.9	0.2	0.0	0.1	0.3	0.0	0.0	0.0	0.3
	03°-40°	2	34	5.0	0.4	0.0	0.1	0.3	0.0	0.0	0.0	0.3
	04°-40°	1	19	2.6	1.1	0.0	0.0	0.2	0.0	0.1	0.1	0.9

1/ In hundreds

Table 15.--Catches of the mothership expeditions for 1951. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees

Month	Lat. Long.	Boat days fished	Hooks 1/ fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
Feb.	01°-55°	46	870	3.3	0.4	0.1	0.0	0.4	0.0	0.1	0.0	0.0
	01°-60°	8	149	3.2	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	02°-50°	1	20	2.5	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	02°-55°	63	1,026	2.7	0.4	0.0	0.0	0.4	0.0	0.1	0.0	0.1
	02°-60°	16	285	3.3	0.3	0.0	0.0	0.4	0.0	0.0	0.0	0.1
	03°-55°	16	221	2.0	0.3	0.0	0.0	0.7	0.0	0.0	0.0	0.2
	03°-60°	10	187	3.3	0.4	0.0	0.0	0.6	0.0	0.0	0.0	0.2
	04°-55°	41	664	2.1	0.5	0.1	0.2	1.1	0.0	0.1	0.0	0.2
	04°-60°	5	93	3.8	0.4	0.1	0.0	0.7	0.0	0.1	0.0	0.2
	05°-55°	13	207	1.4	0.5	0.1	0.0	0.9	0.0	0.0	0.0	0.1
	06°-55°	2	36	1.0	0.9	0.0	0.0	0.7	0.0	0.0	0.0	0.2
Mar.	01°-35°	3	53	2.4	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.5
	01°-40°	7	132	1.6	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.5
	01°-45°	1	18	0.7	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
	02°-35°	5	92	2.7	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.4

Table 15.--Catches of the mothership expeditions for 1951. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks 1/ fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
Mar. (con.)	02°-40°	16	312	2.3	0.4	0.1	0.0	0.2	0.0	0.0	0.0	0.2
	03°-40°	5	96	1.6	0.4	0.0	0.0	0.3	0.0	0.0	0.0	0.4
	03°-45°	1	20	2.2	0.8	0.0	0.0	0.2	0.0	0.0	0.0	0.4
	04°-40°	1	15	0.8	0.9	0.0	0.0	0.3	0.0	0.0	0.0	0.5
Apr.	01°-35°	1	14	4.2	0.8	0.0	0.0	1.0	0.0	0.1	0.0	0.4
	01°-45°	2	36	1.5	0.6	0.0	0.0	0.1	0.0	0.0	0.0	0.2
	01°-50°	76	1,375	2.5	0.5	0.0	0.0	0.4	0.0	0.0	0.0	0.2
	01°-55°	46	892	2.8	0.4	0.0	0.1	0.4	0.0	0.0	0.0	0.2
	01°-60°	1	18	3.0	0.4	0.0	0.0	0.3	0.0	0.0	0.0	0.1
	02°-40°	1	20	0.9	0.5	0.0	0.0	0.2	0.0	0.1	0.0	0.1
	02°-45°	15	276	1.7	0.4	0.0	0.1	0.2	0.0	0.0	0.0	0.2
	02°-50°	51	887	2.2	0.5	0.0	0.0	0.4	0.0	0.0	0.0	0.2
	02°-55°	26	320	2.6	0.4	0.0	0.2	0.6	0.0	0.1	0.0	0.3
	03°-40°	8	150	2.0	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.2
	03°-45°	66	1,126	2.2	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.2
	03°-50°	9	136	1.5	0.9	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	03°-55°	1	20	2.4	0.4	0.0	0.0	0.6	0.0	0.0	0.0	0.0
	04°-40°	4	68	1.6	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.4
	04°-45°	22	391	1.3	0.7	0.0	0.0	0.5	0.0	0.0	0.0	0.3
	04°-50°	22	322	1.4	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.3
	04°-55°	1	19	1.7	0.1	0.0	0.3	0.7	0.1	0.0	0.0	0.3
	05°-45°	11	221	1.7	0.9	0.0	0.1	0.4	0.0	0.0	0.0	0.4
	05°-50°	2	28	1.9	1.1	0.0	0.0	0.6	0.0	0.2	0.0	0.5
	05°-55°	3	50	1.7	0.6	0.0	0.0	0.4	0.0	0.1	0.0	0.4
	06°-45°	3	60	1.4	0.4	0.0	0.1	0.5	0.0	0.0	0.0	0.5
	07°-45°	1	21	0.5	0.7	0.0	0.0	0.4	0.0	0.1	0.0	0.2
	07°-50°	1	18	0.4	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.1
May	01°-50°	28	468	2.5	0.6	0.0	0.0	0.4	0.0	0.0	0.0	0.3
	01°-55°	86	1,486	2.7	0.6	0.2	0.3	0.4	0.0	0.0	0.3	0.0
	01°-60°	91	1,582	2.5	0.4	0.0	0.1	0.3	0.0	0.0	0.0	0.3
	02°-50°	12	212	2.6	0.9	0.0	0.1	0.3	0.0	0.0	0.0	0.3
	02°-55°	42	531	1.7	0.5	0.0	0.0	0.3	0.0	0.1	0.0	0.3
	02°-60°	61	971	2.4	0.4	0.0	0.3	0.4	0.0	0.0	0.0	0.2
	03°-55°	19	343	1.4	0.7	0.0	0.1	0.3	0.0	0.0	0.0	0.3
	03°-60°	12	199	1.1	0.6	0.0	0.2	0.3	0.0	0.0	0.0	0.3
	03°-65°	2	35	4.3	1.1	0.0	0.1	0.8	0.0	0.1	0.1	0.3
	04°-55°	34	558	1.5	0.6	0.0	0.0	0.5	0.0	0.1	0.0	0.3
	04°-60°	50	981	1.3	0.8	0.0	0.1	0.5	0.0	0.0	0.0	0.4
	05°-55°	33	550	1.7	0.6	0.0	0.0	0.4	0.0	0.1	0.0	0.3
	05°-60°	27	524	1.3	0.8	0.0	0.1	0.7	0.0	0.1	0.0	0.5
	06°-55°	3	51	1.5	0.9	0.0	0.0	0.6	0.0	0.0	0.0	0.6
	11°-60°	1	22	3.2	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.1

Table 15.--Catches of the mothership expeditions for 1951. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks[1/] fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
June	01°-50°	30	514	3.8	0.9	0.0	0.1	0.3	0.0	0.0	0.0	0.4
	01°-55°	59	1,056	3.2	0.5	0.1	0.1	0.4	0.1	0.0	0.0	0.4
	01°-60°	18	357	2.6	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.4
	02°-50°	46	756	2.8	0.7	0.0	0.0	0.2	0.0	0.0	0.0	0.3
	02°-55°	53	951	2.7	0.7	0.1	0.1	0.3	0.0	0.0	0.0	0.5
	02°-60°	39	766	2.8	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	03°-50°	23	391	2.8	0.8	0.0	0.0	0.2	0.0	0.0	0.0	0.3
	03°-55°	59	908	3.2	1.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4
	03°-60°	23	386	3.7	0.6	0.0	0.1	0.5	0.0	0.0	0.0	0.4
	04°-50°	5	83	2.4	1.3	0.0	0.0	0.4	0.0	0.0	0.0	0.3
	04°-55°	12	227	2.4	1.0	0.0	0.1	0.4	0.0	0.1	0.0	0.3
	04°-60°	3	34	2.0	0.9	0.0	0.1	0.5	0.0	0.0	0.0	0.2
	04°-60°	2	35	3.9	0.9	0.0	0.0	0.6	0.0	0.0	0.0	0.2
	05°-55°	24	399	2.5	1.0	0.0	0.1	0.3	0.1	0.1	0.0	0.4
	05°-60°	6	106	2.1	0.5	0.0	0.0	0.6	0.0	0.0	0.0	0.5
	06°-50°	1	27	3.3	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.1
	06°-55°	12	246	4.0	1.5	0.0	0.1	0.5	0.0	0.1	0.0	0.4
	06°-60°	2	37	1.0	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.9
	07°-50°	1	24	1.6	0.1	0.0	0.1	0.3	0.0	0.1	0.0	0.2
	07°-60°	1	18	1.2	0.9	0.1	0.0	0.3	0.0	0.0	0.0	0.3
	08°-55°	1	18	1.4	0.7	0.0	0.0	0.5	0.0	0.2	0.0	0.0
	09°-55°	1	18	1.7	1.0	0.0	0.0	2.7	0.8	0.0	0.0	0.0
	10°-50°	2	42	2.6	0.6	0.0	0.0	0.4	0.0	0.0	0.0	0.5
	10°-55°	2	35	2.6	0.8	0.0	0.0	0.7	0.0	0.0	0.0	0.1
	15°-50°	2	24	5.0	0.4	0.0	0.0	0.3	0.0	0.0	0.0	0.4
	17°-50°	1	24	4.6	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	20°-50°	1	24	4.0	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.4
July	01°-60°	25	482	2.0	0.6	0.0	0.1	0.3	0.0	0.1	0.0	0.7
	01°-65°	19	404	2.1	0.9	0.3	0.2	0.4	0.0	0.1	0.0	0.9
	02°-60°	34	566	2.2	0.5	0.0	0.3	0.2	0.0	0.1	0.0	0.8
	02°-65°	32	628	2.3	0.9	0.0	0.1	0.4	0.0	0.1	0.0	0.5
	03°-60°	49	751	3.1	1.1	0.0	0.1	0.4	0.0	0.1	0.0	0.6
	03°-65°	95	1,663	2.3	1.2	0.1	0.1	0.5	0.0	0.1	0.0	0.5
	04°-60°	44	874	2.6	1.1	0.0	0.2	0.3	0.0	0.0	0.0	0.4
	04°-65°	106	2,029	2.3	1.1	0.1	0.1	0.5	0.0	0.0	0.0	0.5
	05°-60°	26	524	1.8	1.0	0.0	0.0	0.6	0.0	0.0	0.0	0.6
	05°-65°	52	912	2.2	1.0	0.1	0.1	0.6	0.0	0.0	0.0	0.6
	05°-70°	37	706	2.4	0.8	0.0	0.0	0.8	0.0	0.0	0.0	0.6
	06°-65°	26	482	2.1	0.8	0.1	0.0	0.8	0.1	0.0	0.0	1.0
	06°-70°	34	665	2.2	0.7	0.0	0.0	0.7	0.0	0.0	0.0	0.6
	07°-65°	13	250	2.3	1.0	0.1	0.0	1.2	0.0	0.0	0.0	1.1
	07°-70°	13	261	2.2	0.8	0.0	0.1	0.7	0.0	0.0	0.0	0.1
Aug.	01°-50°	4	82	1.7	0.3	0.1	0.0	0.3	0.0	0.0	0.0	0.8
	01°-55°	29	559	2.4	0.4	0.3	0.0	0.4	0.0	0.0	0.0	0.6

Table 15.--Catches of the mothership expeditions for 1951. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks[1] fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
Aug. (con.)	01°-60°	6	128	1.7	0.4	0.4	0.1	0.2	0.0	0.0	0.0	0.3
	02°-50°	7	130	2.7	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	02°-55°	62	1,157	2.5	0.5	0.1	0.0	0.3	0.0	0.0	0.0	0.4
	02°-60°	1	22	1.3	0.5	0.1	0.1	0.2	0.0	0.1	0.0	0.3
	03°-50°	9	173	3.0	0.8	0.0	0.1	0.8	0.0	0.0	0.0	0.4
	03°-55°	99	1,811	2.4	0.6	0.1	0.1	0.3	0.0	0.0	0.0	0.3
	03°-60°	14	262	2.1	1.0	0.1	0.1	0.4	0.0	0.0	0.0	0.3
	04°-50°	4	78	3.1	0.9	0.1	0.0	0.4	0.0	0.0	0.0	0.4
	04°-55°	64	1,209	2.0	0.8	0.1	0.1	0.3	0.0	0.0	0.0	0.3
	04°-60°	21	408	2.0	0.9	0.2	0.1	0.3	0.0	0.0	0.0	0.3
	05°-50°	1	22	0.8	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	05°-55°	6	111	2.9	1.0	0.9	0.8	3.1	0.0	0.0	0.0	0.4
	05°-60°	9	162	1.8	0.9	0.1	0.0	0.5	0.0	0.0	0.0	0.4
	05°-65°	9	173	1.6	0.8	0.0	0.1	0.7	0.0	0.0	0.0	0.5
	05°-70°	55	1,049	2.0	0.9	0.1	0.2	1.0	0.0	0.1	0.0	0.9
	05°-75°	2	34	1.2	1.1	0.0	0.0	1.1	0.0	0.0	0.0	0.6
	06°-50°	1	21	1.0	0.7	0.0	0.0	0.3	0.0	0.0	0.0	0.7
	06°-55°	7	135	1.5	1.0	0.1	0.0	0.4	0.0	0.0	0.0	0.6
	06°-60°	3	58	1.3	0.9	0.2	0.0	0.5	0.1	0.0	0.0	0.6
	06°-65°	29	514	1.1	0.8	0.1	0.0	0.8	0.0	0.0	0.0	0.2
	06°-70°	75	1,426	1.1	0.9	0.0	0.0	0.9	0.0	0.0	0.0	0.7
	06°-75°	6	116	1.1	0.7	0.1	0.0	1.1	0.0	0.1	0.0	0.9
	07°-55°	1	19	0.6	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.3
	07°-65°	22	414	1.3	0.5	0.1	0.1	0.9	0.0	0.0	0.0	0.8
	07°-70°	45	842	1.3	1.0	0.1	0.1	1.0	0.0	0.0	0.0	0.9
	07°-75°	30	568	0.4	0.7	0.1	0.0	0.6	0.0	0.0	0.0	0.6
	08°-65°	9	178	1.1	0.6	0.0	0.0	0.9	0.0	0.0	0.0	0.7
	08°-70°	21	372	0.7	1.3	0.0	0.0	0.9	0.0	0.0	0.0	0.7
	08°-75°	50	897	0.5	1.3	0.1	0.0	0.9	0.0	0.0	0.0	0.4
	09°-65°	1	18	1.0	0.7	0.1	0.0	0.0	0.7	0.0	0.0	0.5
	09°-70°	11	230	0.9	1.7	0.0	0.0	1.1	0.0	0.1	0.0	0.1
	09°-75°	9	163	0.4	2.0	0.1	0.0	1.0	0.0	0.0	0.0	0.6
	10°-65°	1	18	1.2	0.7	0.0	0.0	0.9	0.0	0.0	0.0	0.2
	10°-70°	5	102	1.4	1.3	0.1	0.2	1.0	0.0	0.0	0.0	0.0
	10°-75°	8	144	0.4	1.6	0.1	0.0	1.1	0.1	0.1	0.2	1.1
	11°-65°	1	18	0.3	0.9	0.2	0.0	0.9	0.0	0.0	0.0	0.6
	11°-70°	4	74	0.4	1.2	0.0	0.0	0.6	0.0	0.0	0.0	0.0
	11°-75°	4	70	0.9	1.6	0.1	0.0	1.2	0.0	0.0	0.0	0.9
	12°-65°	2	35	0.1	0.2	0.0	0.0	0.9	0.0	0.0	0.0	0.8
	12°-70°	1	20	0.2	0.8	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	25°-70°	2	37	0.1	0.2	0.1	0.0	0.6	0.0	0.0	0.0	0.7
Sept.	01°-55°	37	811	2.0	0.7	0.4	0.0	0.3	0.0	0.0	0.0	0.5
	01°-60°	19	341	1.7	0.7	0.7	0.2	0.3	0.0	0.0	0.0	0.4
	01°-65°	15	322	1.5	0.5	0.6	0.0	0.4	0.0	0.0	0.0	0.6

Table 15.--Catches of the mothership expeditions for 1951. Catches are lumped by blocks of 1° of latitude and 5° of longitude with each block identified by its SW coordinates. All locations are N. latitude and E. longitude less 100 degrees (cont'd)

Month	Lat. Long.	Boat days fished	Hooks[1] fished	Catch per 100 hooks								
				Yellow-fin	Big-eye	Alba-core	Skip-jack	Black marlin	Striped marlin	Sail-fish	Broad-bill	Sharks
(Sept. con.)	02°-50°	2	37	2.4	0.2	0.0	0.0	0.6	0.0	0.0	0.0	0.5
	02°-55°	57	1,056	2.6	0.5	0.4	0.0	0.4	0.0	0.0	0.0	0.4
	02°-60°	66	1,215	2.3	0.6	0.6	0.1	0.4	0.0	0.0	0.0	0.3
	02°-65°	35	715	1.6	0.6	0.6	0.0	0.4	0.0	0.0	0.0	0.6
	03°-50°	4	73	2.2	0.3	0.0	0.0	0.4	0.0	0.1	0.0	0.4
	03°-55°	20	315	2.1	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.3
	03°-60°	80	1,461	2.4	0.9	0.3	0.0	0.3	0.0	0.0	0.0	0.3
	03°-65°	34	681	1.4	0.7	0.1	0.1	0.3	0.0	0.0	0.0	0.5
	04°-55°	4	70	1.8	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.4
	04°-60°	37	651	1.9	1.0	0.1	0.1	0.3	0.0	0.0	0.0	0.4
	04°-65°	46	776	1.6	0.9	0.1	0.1	0.3	0.0	0.0	0.0	0.4
	05°-50°	1	18	1.2	0.4	0.1	0.0	0.3	0.0	0.1	0.0	0.5
	05°-55°	7	123	2.2	1.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4
	05°-60°	6	116	1.4	1.7	0.2	0.1	0.2	0.0	0.0	0.0	0.5
	05°-65°	27	434	1.0	0.8	0.0	0.1	0.6	0.0	0.0	0.0	0.5
	05°-70°	12	224	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.7
	05°-75°	1	18	0.2	1.2	0.1	0.0	1.2	0.0	0.0	0.1	1.7
	06°-55°	2	40	0.9	0.9	0.0	0.0	0.5	0.0	0.0	0.0	0.4
	06°-65°	22	394	0.7	0.9	0.0	0.1	0.6	0.0	0.0	0.0	0.8
	06°-70°	23	368	0.8	0.7	0.0	0.1	0.7	0.0	0.0	0.0	0.8
	07°-65°	4	58	0.6	0.9	0.0	0.1	1.0	0.0	0.0	0.0	1.5
	13°-60°	1	21	2.2	0.2	0.6	0.2	0.6	0.0	0.2	0.0	0.1
	14°-65°	1	18	0.5	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.2
	24°-55°	4	72	0.3	1.1	0.1	0.1	0.9	0.0	0.0	0.0	0.0
	24°-60°	2	42	0.4	0.5	0.1	0.2	0.6	0.0	0.0	0.0	0.5
	25°-55°	1	18	0.1	0.3	0.9	0.0	1.0	0.0	0.0	0.0	0.1
	25°-70°	4	76	0.2	0.2	0.1	0.0	1.0	0.0	0.0	0.0	0.6
Oct.	02°-65°	15	182	1.6	0.5	0.1	0.0	0.6	0.0	0.0	0.0	0.1
	03°-65°	29	294	1.8	0.4	0.1	0.0	0.9	0.0	0.0	0.0	0.1
	04°-65°	1	16	1.0	1.1	0.0	0.0	0.6	0.0	0.0	0.0	0.0
	05°-70°	5	88	0.3	0.5	0.0	0.1	0.6	0.0	0.0	0.0	0.7
	05°-75°	49	927	0.6	0.7	0.0	0.1	0.6	0.0	0.0	0.0	0.6
	06°-65°	2	42	0.8	0.5	0.2	0.0	0.4	0.0	0.0	0.0	0.0
	06°-70°	16	279	0.7	0.7	0.1	0.1	0.6	0.0	0.0	0.0	0.8
	06°-70°	1	18	0.5	0.8	0.0	0.2	1.2	0.0	0.0	0.0	1.0
	06°-75°	156	2,923	0.6	0.7	0.0	0.1	0.7	0.0	0.0	0.0	0.6
	07°-70°	4	78	0.3	0.8	0.0	0.0	0.5	0.0	0.0	0.0	1.0
	07°-75°	81	1,408	0.5	0.7	0.0	0.1	0.7	0.0	0.0	0.0	0.8
	08°-70°	2	42	0.2	0.7	0.0	0.0	0.5	0.0	0.0	0.0	0.7
	08°-75°	43	753	0.3	0.7	0.0	0.0	0.6	0.0	0.0	0.0	0.9
	09°-70°	5	85	0.2	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.2
	09°-75°	32	591	0.3	0.9	0.0	0.1	0.5	0.0	0.0	0.0	1.2
	10°-75°	22	399	1.0	1.1	0.0	0.0	0.6	0.0	0.0	0.0	0.9

[1] In hundreds

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TUNA LONGLINE FISHERY AND FISHING GROUNDS

By

Hiroshi Nakamura, D. Sc.

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THE TUNA LONGLINE FISHERY AND ITS FISHING GROUNDS

by

Hiroshi Nakamura

Introduction

The Japanese tuna fishery, which formerly had for its fishing grounds almost the whole western Pacific and a part of the Indian Ocean, wherein its small vessels roamed at will, was reduced by the Pacific war to such a nearly complete state of destruction that little was left to remind one of its former condition.

On the one hand it was forced to accept restrictions which can only be called mortal in the form of an iron chain of limitations upon its fishing areas, and on the other hand it lost a large number of fishing vessels and the excellent advanced bases in Okinawa, Formosa, the Ogasawara Islands, and the mandated South Sea islands. With even the materials necessary for fishing difficult to obtain, the problems faced by this fishery were certainly not easy ones.

When we look at the course taken by this fishery from the end of the war to the present day, we see that despite the many difficulties and obstacles mentioned above the tonnage of its fishing vessels has already in a comparatively short period recovered to a level close to that of before the war. This fact demonstrates the unstinted efforts of the people engaged in this fishery, efforts which are truly worthy of admiration. However, considering this situation coldly, we must also admit that the rapid tempo of recovery in this fishery reflects the confusion in Japanese fisheries circles after the war and the fact that this fishery became the object of investment as a measure to relieve the depression in other industries. Consequently, it can hardly be said that this fishery has undergone a substantially healthy recovery. In fact, it has a character which can hardly be considered under the heading of rapid progress. Now, 4 years after the war, the tuna industry cannot be said to be as promising as was hoped at the beginning of its new start, but it appears rather to be fraught with many problems and hardships.

The cause of these problems and hardships is probably the same as that of the hardships which beset the Japanese fishing industry as a whole, that is the restriction on fishing grounds. In part too it should probably be considered due to the overall abnormality of the Japanese fisheries in recent years caused by so-called oceanographic abnormalities.

Because the waters opened to Japan's fisheries are largely those off her Pacific coast, a good deal of objectivity can probably be detected in the fact that the tuna fishery has been temporarily in the spotlight and has come in for a great deal of attention. When we come to the question of how much of a scientific nature there was in the manner in which this attention was given to the fishery, we cannot unfortunately give any answer. The sad fact is that we have hardly any scientific knowledge which could have been considered in connection with this fishery. Expressed concretely, what we mean by knowledge of a scientific nature would be such things as how many vessels should be permitted to operate in the waters allowed to us, in view of the size of the resources, and how much they could be expected to produce. With regard to such questions, is there not at present almost no one who could give an accurate analysis?

The tuna, along with the snapper and the carp, is among the fish with which the Japanese are best acquainted, its name being known even to 3-year-old children. However, scientific knowledge concerning these fishes is extremely poor and this fishery can be thought to be the most primitive in character which we have.

The reasons why the tuna fishery is productively at an extremely low ebb are set forth in this book in the section on the characteristics of the tuna fishery, but to put it briefly, it is because this fishery is largely lacking in planability or stability. The reasons for this are that, because the range of distribution of the fishes which are the object of the fishery is extremely broad and these fishes perform migrations on a large scale, not only can the essential nature of the resource not be easily grasped, but the investigation of the paths of the migrations and the factors controlling them are accompanied by remarkable difficulties and require great expenditures: for which reason we can hardly be said to have any knowledge concerning these phenomena.

Up to the end of the war the writer spent over 10 years in Formosa, where he was mainly occupied in the study of the ecology of these fishes. After the war he was ordered to undertake the study of the resources of the tuna fishery at this research station, in which work he is presently employed. In order to determine research policies corresponding to the new conditions, the author has attempted to bring together data from tuna fishing experiments and fishing ground surveys carried on by fishery research agencies throughout the whole country during more than 10 years past. The object has been to see if it were possible by means of these data to get some knowledge concerning the migrational patterns and the stock and thereby to make some contribution to the stabilization of the tuna fishery. What has been accomplished in regard to these problems is, however, very little.

In the beginning the intention was only to write concerning the data referred to above, but the decision was made to cover in outline fishing gear, fishing methods, and other general matters concerning the tuna fishery. Consequently, the work is in part a repetition of some of the material in the author's book, The Tuna and Their Fisheries, published by the Takeuchi Book Store.

The tuna fishery is at present in a somewhat congested condition, but unlike other fisheries its fishing grounds are extraordinarily broad and are for the most part on the high seas away from territorial waters. What sort of treatment Japan's tuna fishery will receive in the future when the peace treaty is concluded, I do not know in the least. However, if the general international concept of the high seas continues to be guaranteed in the future, the time will surely come when this fishery will be permitted to operate freely. Until that day I hope to continue studying the essential character of the resource insofar as I am able, and attempting to contribute to the establishment of a planned, stabilized tuna fishery without any diminution of the resource. Corrections and contributions of data from the readers are requested.

I have dared to undertake the writing of this report, despite my lack of talent, in the hopes that my little knowledge and feeble effort might be of some use. A direct motive has been the urging of the director of this station, Dr. Morisaburo Tauchi, from whom I have received various assistance. I wish here to express my deep thanks to him. (January 2, 1948)

P.S.

During the writing of this manuscript a great revolution in fisheries research agencies has taken place, the former Fisheries Experiment Station of the Ministry of Agriculture and Forestry has been abolished, and the regional fisheries laboratories have been established. The writer has been appointed director of the Nankai Regional Fisheries Research Laboratory. Consequently, this report, which was to have been published by the Fisheries Experiment Station of the Ministry of Agriculture and Forestry, has been changed to a report of the Southern Regional Fisheries Research Laboratory.

March 30, 1950)

I. Types of Fisheries and Their General Description

There are three major types of fisheries for the tunas and spearfishes. The first is the net fishery, the second the hook and line fishery, and the third is the harpoon fishery.

A. Net Fisheries

There are two types of net fisheries having the tunas as their object. The first is that called the set-net or trap fishery, where the net is permanently fixed at a definite location. The second includes fisheries using movable nets, not fixed in one place, and it comprises round haul nets, drift nets, and gill nets.

1. Stationary net fisheries

An example is the large set-net. This type of net is held at one location by the use of anchors and floats and sinkers, so it is necessary that the place where the net is set up be not very deep. As it is naturally impossible to move the net at will, unless it is set up across paths travelled by the fish, it will be difficult for it to attain its objective of catching fish.

These two conditions place basic limitations on the establishment of this type of fishery. Places which fulfill these conditions are not to be found everywhere but are naturally extremely limited.

Places which meet the above two requirements, that is, locations suitable for the set-net fishery, are either on coasts where the water is comparatively deep close to shore, where the effect of run-off from the land is small, and where the coast faces directly on areas of warm current, or they are at places having such topography as the tips of capes or peninsulas at the mouth of large bays. However, even if these conditions are perfectly met, if the current and tides in the area are very strong, it will be impossible to set up the gear and the location will, of course, be unsuitable as a fishing ground.

Thus this type of gear does not have the positive character of chasing and catching the fish, but rather waits for the fish to come of its own accord into the net. Consequently, because of changes in oceanographic conditions and abnormalities in the weather, even though a net of the same construction is set up in exactly the same place, the catch will be good or bad from year to year and fluctuations in the catch will be difficult to avoid. The catch of such gear is not limited to the tunas, but other fish such as yellowtail and skipjack large enough to enter the net will all be taken by this type of fishery.

As this net is on a large scale it requires a considerable amount of capital to establish one. It may be thought that large sums of money can be earned in the course of one night with this type of gear, but when poor fishing continues for sometime and there is damage from rough weather, it is often found that one fine morning the whole property has been lost.

As the figure shows (Translator's note: figure omitted), the net consists of two parts, the lead and the heart. The lead cuts off the path of the fish and acts to direct them into the heart.

When a tuna comes swimming along and encounters the lead, he is frightened by the net and tries to escape, follows the net out to sea, and at last enters the heart of the trap. When fish enter the heart of the trap, a lookout who is on watch signals at an appropriate time to the tender boat. The boat is standing by the mouth of the heart and when the signal is received the men in the boat quickly close the opening of the heart so that the fish cannot escape. They then gradually haul the net in such fashion that the fish are driven into the bunt from which they are brought into the boat by means of gaff hooks.

There are among the tunas, as is set forth in a later section, several species. The different species each have their different habits. The bigeye tuna, the albacore, and the yellowfin tuna do not often approach coasts suitable for the use of large set-nets and therefore they are hardly taken by this type of fishery. Immature yellowfin, however, do tend to enter coastal waters and at their immature stages they are often taken. The black tuna and some of the spearfishes characteristically enter coastal water areas and therefore the catch of the set-net is principally these species.

It is not known when or by whom the set-net was invented and put into actual use. However, it is certain that the invention and application of this gear took place an extremely long time ago. The tuna trap shown in the figure is extracted from the Nippon Suisan Saihoshi[1] and the outline of its construction is as follows.

"A large net in the county of Kochika in the province of Rikuzen is designed chiefly to take tuna, however, as it is a fixed fishing gear snappers, yellowtail, sardine, skipjack, tuna, and sharks all enter it.... The fishing ground is at the point of a cape where trees grow luxuriantly and where the coast line forms a rounded bay. It is located over 400 ken (200 yards) from shore in waters 25 - 26 fathoms deep and is set up in such a way as to embrace the mouth of the bay. The local tradition concerning the origin of this net ascribes its invention to one Saburō Torimi of the Abe clan, who taught the method to the fisher-folk. Under the old Sendai feudal lords, the net was insured by a grant of money from the local ruler for the repair of the net when it was damaged by stormy weather."

The catch of tunas by fixed gear according to statistics of the Ministry of Agriculture and Forestry for 1941 amounted to a total of 9,258,324 pounds. According to the same statistics, regions in which the catch amounted to over 10,000 kan (82,700 pounds) were as shown in the following table. From 1942 on the migrations of black tuna into Japanese coastal waters dropped off markedly, and for this reason the catch of tunas by fixed gear has diminished to almost nothing.

Table 1.--Catch by fixed gear in various regions (in pounds)

Region	Catch	Region	Catch
Hokkaido	2,050,629	Fukui	182,279
Iwate	2,919,781	Shizuoka	135,430
Akita	1,087,505	Tottori	619,357
Miyagi	558,605	Ehime	149,844
Toyama	144,799	Kochi	162,911
Ishikawa	156,055	Nagasaki	138,307

Notes: (1) According to Ministry of Agriculture and Forestry statistics for 1941.
(2) Only those prefectures having a catch over 10,000 kan (82,700 pounds) are shown.

2. Drift-net fishery

In this fishery, unlike the trap fishery, the nets are loaded into the fishing boat and carried to the place where they are to be used. Consequently, it has the characteristic of mobility, and can be said to be of a more positive character than the trap fishery.

In catching small birds a so-called "mist net" is used, and the drift-net may be thought of as a mist net used in the sea. In short, the net is stretched across the path of the fish, and waits for passing fish to be caught in it.

Tuna generally swim in the direction of flow of the current, and therefore the net must be set roughly at right angles to the current. Furthermore, as the depth of the net is quite insignificant in comparison with the depth of the sea, it goes without saying that it can take only those fish which swim at the very surface. Consequently unless this gear is used at a place and at a time where the tunas swim in the surface layer, it will not attain its objective of catching fish. Also, the tunas naturally have the power of sight, and when they encounter a net, they will try to escape, so this gear is useless unless employed at night, when the meshes of the net cannot be seen.

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[1] Published by the Fisheries Bureau of the Ministry of Agriculture and Commerce in 1910. The author has supplied suitable diacritical marks to assist in the reading of the Chinese-style text of the description.

The factors which control the vertical distribution of the tunas are thought to be principally such things as light, temperature, and water pressure. As far as light is concerned, fishes in general share the characteristic of inhabiting deeper levels during the day than during the night. This characteristic appears also in the tunas, and is particularly marked in the case of the bigeye tuna.

With respect to temperature, the majority of tuna species are basically warm-water fishes, preferring to inhabit sea areas having warm waters. They are thought to be extremely sensitive to changes in temperature, but this means only that the limits of the temperature at which they will live are clearly marked, and does not mean that the range of temperatures which they can withstand is narrow. It is thought that the range of temperatures which they can endure is rather broad. It is known in the waters of the low latitudes they generally swim at fairly deep levels. In such areas temperatures at which the tunas can live are found at the surface, at the 100-meter level, and in some cases even deeper. From an examination of a considerable amount of data, it appears that in the waters of the low latitudes, the tunas are generally most abundant in the vicinity of the 100-meter level. Compared with the temperatures which are thought to be most favorable for the occurrence of tuna in Japanese waters, the water temperatures at the 100-meter level in tropical seas are rather high. This fact is thought to show that in some circumstances the effect of water temperature on vertical distribution is not very great, indicating that the action of light is more important. The above-expressed opinion that the density of distribution is greatest in the vicinity of the 100- meter level is not actually based on any study of the density of distribution, but rather on the circumstances under which catches are made in the longline fishery, and therefore it may naturally be thought that the strength of the light rays may be a factor in making the fish easier to catch. However, at present it is impossible to conclude whether light or temperature is the most important factor in determining the vertical distribution of the tunas.

As far as water pressure is concerned, the adaptability of the tunas to changes in this factor is thought to be extraordinarily great. In tropical waters, for example in the Celebes Sea, they occur in considerable density as deep as well over 100 meters, and they also occur practically on the surface. In short, it is thought that they can withstand water pressures ranging from about 1 to well over 10 atmospheres.

Other fishes are known which can withstand considerable changes in water pressure where the changes occur gradually, but ordinarily they cannot withstand sudden changes. The tunas, however, are thought to have remarkable resistance against sudden changes in water pressure. For example, if we look at the behavior of tunas when they are hooked, we see that they sometimes make one deep dive, going so deep that the glass ball which is used as a float is crushed by the water pressure. As was noted above, in tropical sea areas the identical species is distributed at markedly greater depths than it is in waters of higher latitudes, and is thought to be able to withstand more violent changes in external pressure, for which reason it can be concluded that the effects of external pressure are not very important in determining the vertical distribution of the tunas.

It has already been stated that temperature and light are the main causes of the vertical movement of the fish. In Japanese waters, off Hokkaidō and the northeastern coast of Honshū, a warm current forms a shallow layer on the surface, below which runs the cold current of the Oyashio. In waters presenting oceanographic conditions of this sort, the tunas naturally are distributed only in the surface layer, affording favorable conditions for the drift-net fishery.

A boat which has arrived on the fishing ground sets nets in the evening. As was stated earlier, the net is set at a right angle to the flow of the current. Buoys are attached to the net, as shown in the figure, and a line called the myakuzuna ("pulse-line") is fastened to the boat, which turns its bow upcurrent and drifts, waiting for the fish to strike the net. The myakuzuna not only performs the function of connecting the boat and net, but it also transmits to the boat the impact when the tunas strike the net. The hauling in of the net and the taking of the fish are generally begun at dawn, but when the catch is large the nets may be hauled several times during the night.

This fishery has completely decayed in recent years, and there are no boats engaged in it at present.

(Translator's note: figure 2, a rough sketch of a drift-net, is omitted.)

3. Round haul net fisheries

This type of fishery can be said to have an even more positive character than the drift-net fishery. In fact it can be said to be the most positive of all the tuna fisheries. There is one method which has been in use in Japan since ancient times, and another, the American-type purse seine, which has been imported from America in recent years. Concerning the old method, the following description has been abridged from the Nippon Suisan Saihoshi.

Ordinarily from three to five boats form a team, with 10 to 15 fishermen on each boat. Arriving on the fishing grounds these boats separate and quickly surround an area of the sea with their nets, cutting off the escape of the tunas and finally driving them into the bunt of the net.

The American-type purse seine has already been in use for over 20 years in America and its use is increasing from year to year, the catch by this method having gradually approached and in some regions surpassed that from the pole and line fishery. The catch appears to be mainly young tunas and skipjack.

This fishing method was imported into Japan after the end of the second World War. In 1948 the Suisan Kenkyū Kai, in cooperation with the Tokyo Fisheries Company, tested this fishing method with the Shiroyuri Maru (100 tons). During the trial period of about 1 month a total of about 80 tons of skipjack and tunas (about 21,000 kan) were taken, attesting the feasibility of this fishing method. In 1949 five purse seiners fished and took about 744,300 pounds. The principal catch was skipjack and young bigeyed tuna.

The construction of the gear varies depending upon the type of boat, but figure 3 shows one type in use (Translator's note: figure omitted). The following table lists the materials employed.

The materials used in the net shown in figure 3 are listed in the following table. (knotless net was used).

When a school of fish is sighted, the net is set so as to cut across the line in which they are moving, it is hauled around the school, the lead line is pursed up, and the fish are captured. These operations are almost entirely carried out by the use of machinery, making the operation extremely efficient.

The fishing grounds up to the present have been almost completely limited to the waters off northeastern Japan. As this area presents oceanographic conditions which make the tunas and skipjack swim in the surface layers, it is well suited to this fishery. The question of whether or not this fishery can be established in the warm currents of the south, where oceanographic conditions are different, can only be clarified by future experimentation.

Table 2.--Materials required for an American-style purse seine

Item	Type			Quantity	Unit weight 100 meshes, 600 ft.	Total weight
	Size (thread)	Mesh (sun)*	Depth (meshes)			
					kan*	kan*
20-count cotton	90	4	100	600 x 2	33,600	367,200
"	70	3,5	100	600 x 7	23,800	999,600
"	120	6,5	50	600 x 1	40,800	244,800
Total						1,611,600
20-count cotton	(spares 20%)					320,000
"	(for repair 5%)					80,000
"	(for sewing 3%)					50,000
Total						2,061,600
Rope						4,000 pounds
Wire rope						1,000 kg
Lead						2,000 kg
Rubber						300 kg
Coal tar						6,000 kg

Note: This table and figure 3 are both taken from the Suisan Kenkyū Kaihō No. 2, November 1949.

(Translator's note: *1 sun = 1.2 inches **1 kan = 8.27 pounds)

The amount of the catch by the drift-net fishery is not known, but according to Ministry of Agriculture and Forestry statistics for 1941 the catch by round haul nets was 1,627,263 pounds. This was about 1/6 as much as the catch by set-nets for the same year.

B. Hook and Line Fisheries

The mainstay of the tuna fisheries at present are the hook and line fisheries. If, for example, we consult the statistics of the Ministry of Agriculture and Forestry for 1941, we find that the total catch of the net fisheries was about 10,751,000 pounds, while the catch by the hook and line fisheries, as shown in the following table, was about 6 times as great.

Table 3.-- Tuna catch by the hook and line fisheries (Ministry of Agriculture and Forestry statistics, 1941)

Type of Fishery	Amount of Catch (pounds)
Longline fishery	51,524,606
Pole and line fishery	12,867,797
Total	64,392,403

The above table gives only the tuna catch, but the longline fishery took in addition 13,298,061 pounds of spearfishes, giving a combined total for tunas and spearfishes of 77,690,464 pounds. In addition it is estimated that the shark catch by the longline fishery amounts to around 45,485,000 pounds, so if all of these are included, the catch will be a little less than 124,050,000 pounds.

The hook and line fisheries are, as shown in table 3, divided into the longline fishery and the single line fishery, the latter being further divided into trolling and pole and line fisheries.

1. Trolling

In trolling a number of lines are paid out from the fishing boat with artificial lures or baited hooks attached to their ends. The boat runs back and forth pulling these lines and captures tunas, bonitos, and spearfishes. The use of hooks with artificial lures is like the use of flies in fishing in streams. Various forms of artificial lures are used, depending upon the type of fish sought and the locality. (Translator's note: figure 4, a sketch of a trolling jig, is omitted.)

This is a fishery which is carried on widely, not only in Japan but also in Europe, America, Indonesia, and Micronesia, and everywhere upon exactly the same principles. The contrivances used in this type of fishing in America are more refined than those employed in Japan. Two or three feet ahead of the lure they attach what is called a "teaser." When the gear is trolled, the teaser appears to be a small animal being pursued by the lure, which is in turn seized by the tuna or skipjack. This is a very rationalized system and is probably advantageous because of the greater visual stimulus to the fish, but it is not known whether or not it improves the catch because there are no data from comparative experiments. It is recorded that the natives in the New Guinea area catch fish by using a kite made of *nipa* palm leaves to the tail of which a fish hook is attached.

Throughout Japan the trolling fisheries are just small scale coastal fisheries using small boats. The main items in the catch are skipjack, *Auxis*, *Sarda*, young tuna, dolphin, and cybiids. However, it is reported that in the times when black tuna occurred in very large numbers on the fishing grounds around Tanegashima and off Hokkaido, a rather large amount of black tuna was taken by this method. Aside from these vessels that specialize in trolling, the longline vessels in most cases troll one or two lines on their way to and from the fishing grounds.

2. Pole and line fisheries

In these fisheries poles are used to catch fish by hand. The tunas taken by these fisheries are mainly albacore and the young of other species. However, as will be described later, under some circumstances fairly large fish are also taken.

The number of fishermen varies with the size of the boat, but it runs from 10 to 30 or more. The boats have live-wells in which sardines are kept to be used as live bait. When the boats arrive on the fishing ground and a school of tuna is sighted, bait is scattered to concentrate the fish, which are then caught using either artificial lures or baited hooks.

The fishing method is exactly like that used in taking skipjack. When the schools consist of large tuna, two fishermen sometimes work together as a team. As figure 5 shows (Translator's note: figure omitted), the lines from two poles are joined together and attached to a single hook. As this means that the number of hooks is cut in half it might be thought inefficient, but since even slightly large tuna cannot be easily brought into the boat by the strength of one man, this use of two-man teams actually results in greater efficiency. By this method even large fish of about 30 kg weight can be lifted into the boat with one swing.

In America, as has already been stated, purse seining and pole and line fishing are the main methods employed in catching tuna, there being no longline fishery. It appears that plans are already being made for the advance of this fishery into the former South Seas Mandate area, and studies are being made of the distribution of bait and of tunas and skipjack.

Compared to the tuna longline fishery, this method has the advantage on the score of the exertion required of the individual fisherman, however, the essential weakness of this fishing method lies in the fact that it always requires live bait. According to the above-mentioned report of American explorations in the waters of the former South Seas Mandate, the establishment of this fishery in that region appears doubtful because of the bait problem. However, as everyone knows, the waters of that region are an excellent fishing ground for the longline fishery. The value of those fishing grounds will be discussed in a later section.

3. Drift line (nagashiyoma) fishery

This fishery has been carried on in the past, but it is not known whether it is at present. A brief account of it is given here because its concept contains some very interesting features. It is called nagashiyoma in the Nagasaki area and nagashinawa in the Izu region.

The fishing gear consists of a barrel, line, and hook. The barrel performs a double function as a float and a reel, with the line wound around it. A hook is attached to the tip of the line exactly as in the case of the longline, which will be described later, with a wire leader and a sekiyama. For bait sardines and squid are mainly used, and the gear is chiefly employed with the object of catching albacore (Translator's note: figure 6, depicting this gear, is omitted.)

When the hook has been baited, the line is paid out to a suitable length and allowed to hang down into the sea, the remainder of the line being then secured either to the barrel or upon itself with a thin string so that no more will unreel off the barrel. The string used for stopping the line must be neither too strong nor too weak. When a tuna takes the hook and begins to fight, it is necessary that the string be strong enough to set the hook thoroughly in the fish's mouth. When the hooked tuna attempts to dive deep, the string must be of such strength that it will break from the combined force of the buoyancy of the barrel and the pull of the fish.

When a tuna is hooked, the string breaks and the barrel spins violently, paying out the line. The fishing boat, which is standing by, immediately is rowed to the barrel and the line is pulled in by hand. The spinning of this barrel is described in old books as being just like a mill wheel.

Ordinarily one boat operates about 8 tubs, which are set in a line at suitable intervals. This is thought to have been the origin of the longline, which will be described later, but the relationship is not well known.

When the tunas are hooked, they tend to dive violently and deep. If the tub with its great buoyancy were acting directly as a float, there would be danger of the line's parting. On the other hand, if a float of small buoyancy were employed, there would be danger of its being pulled under by the fish. The idea of fastening the line to the barrel with suitable string, having this string broken by the pull of the tuna, and having the barrel revolve and pay out the line is the same in principle as the modern reel.

The catch of the hook and line fishery was mentioned earlier, the amount exceeding the catch by all net fisheries for the same year. Prefectures with a catch of over 10,000 kan (82,700 pounds) and the amount of their catch are given in the following table.

Large catches are shown for Miyazaki, Kagoshima, Shizuoka, and Okinawa prefectures. This pattern corresponds at many points with the skipjack landings, showing the relatedness of these two fisheries.

Table 4.--Tuna catch by hook and line fisheries in various localities (1941, Ministry of Agriculture and Forestry statistics)

Locality	Catch (pounds)	Locality	Catch (pounds)
Miyagi	1,045,957	Fukushima	250,689
Chiba	119,105	Tokyo	156,683
Kanagawa	160,769	Shizuoka	2,640,495
Mie	1,077,912	Wakayama	505,371
Tokushima	198,166	Kochi	197,405
Nagasaki	134,942	Miyazaki	4,024,959
Kagoshima	1,387,590	Okinawa	874,280

4. Longline fishery

The longline fishery is the most important of the tuna fisheries, both in terms of the scale on which it is prosecuted and in terms of the catch.

The gear is built around one trunk line to which float lines (*ukinawa* or *abanawa*) and branch lines are fastened. In the old days hemp was used as material for the lines, but at present cotton is generally employed. The gear used in the spear-fishery of Kagoshima Prefecture employs lines of about 7 *momme* weight, but ordinarily 9 *momme* or 10 *momme* line is employed. This designation shows the weight in *momme* of five *shaku* of line (*1 momme* = 0.1325 ounce, 1 *shaku* = 1 foot).

The thickness of the line used has gradually increased in recent years, the main reason being the increase in the size of fishing boats with the increase in the number of units of gear used as another reason. At the end of the branch line a *sekiyama* is attached with a swivel. Formerly the *sekiyama* was made of a heart of high-grade Noshū hemp wound with cotton line, but at present this is hardly used at all, the ordinarily employed *sekiyama* being made of nine strands of No. 28 steel wire wrapped with cotton. A wire leader is attached to the end of the *sekiyama*. This leader is usually nine strands of No. 27 steel wire, but some fishermen claim that seven strands of No. 25 wire is best. The hook is attached to the end of the leader wire.

A glass ball 30 cm in diameter, with walls 8 mm thick, wrapped in netting, is attached to the float line as a float. Sometimes billets of paulownia wood about 3 inches in diameter are used as floats. In recent years iron or aluminum ball floats have come into use. The floats combine the functions of supporting the line, signaling the presence of fish on the line, and identification. The float functions and the marker functions are the most important. Ordinarily a flag of cloth or of palm fiber is attached to a bamboo pole to mark the float. At night in order not to lose sight of the line, light buoys are attached here and there. Formerly carbide lamps were used for this purpose, but at present battery-powered lights are generally used. As the disappearance of the line means a very serious loss, recently such plans as the attachment of a device to the float to transmit electrical waves which could be received by the fishing boat have been devised and will probably be put into actual use in the near future.

The construction of the lines varies depending on the type of fish sought, the locality, or the individual fisherman, but the basic form is invariable. In any case there is a single main line with a number of branch lines and float lines made so as to hang the hook at a suitable depth.

Gear is ordinarily counted in terms of baskets or of skates. Formerly each section of line was put away separately in a basket, but these are hardly used at all at present because of their bulk. The unit of gear is a hold-over from this former practice.

The length of the main line of one basket is subject to various changes, but those in use at present are generally of about 300 meters. To this usually one float line is attached. The float line's length is not fixed but can be suitably adjusted depending on the fishing ground. The branch lines in common use at present have a cotton part of about 15 meters, and sekiyama and wire leaders of 3 to 5 meters each. This, however, is not invariable but differs with oceanographic conditions and the species of fish that is sought. A particularly marked example of variation is found in the gear used for black tuna in Miyazaki Prefecture, in which each basket has only one branch line, a rather long one. In gear designed to take spearfishes and albacore generally the branch lines are short and numerous, there sometimes being more than 10 branch lines in one basket. In recent years, however, even albacore lines show a trend toward longer branch lines and a smaller number per basket. The reasons are thought to be related both to the supply of material and to catch rates.

The number of units of gear employed at one time varies with the size of the vessel, in recent years it has increased rapidly so that the large boats are actually using 300 to 350 baskets. Assuming that each basket has 5 hooks, the number of hooks fished each time ranges from 1,500 to 1,750. If the length of the main line is, for example, 300 meters, the total length of the gear will be 90 to 100 kilometers. In actuality the main lines are not stretched taut but sag about 60 percent. The use of such large quantities of gear is principally for the purpose of increasing the catch per day, but it can also be thought to increase the chance of the line's encountering schools of fish. However, as considerable strain is put on the material, this cannot help shortening the life of the line.

If the scale of operations outlined above is compared with the trolling and pole and line fisheries, it should be clear that the longline fishery is in quite a different category as far as the size of the undertaking is concerned.

Both large and small vessels are engaged in this fishery. Before the war vessels in the 200-ton class were being constructed. Since the war there are some boats in the 200-ton class, but the majority of them have followed the standards for the 45, 75, 90, and 135-ton classes. The present fleet numbers 1,236 boats, with a total tonnage of 101,260.26 tons and total horsepower of 192,233.6. The following table gives a breakdown.

This fishery has grown up in very close association with the skipjack pole and line fishery. In the past the boats engaged in the skipjack fishery during the summer have shifted to this fishery during the winter, however, in recent years there has been a tendency for the number of fishing boats specializing in this fishery to increase and about 25 percent of the boats listed above are full-time tuna longliners.

As the large vessels ordinarily require 60 days or longer per voyage, they can make about 4-1/2 to 5 cruises per year. Hitherto the catch has generally been preserved by means of ice, but recently there has been a tendency toward a gradual increase in the number of vessels equipped with refrigeration machinery.

Having completed the loading of provisions, drinking water, fuel, fishing gear, bait, and ice, and with all preparations complete, the vessel leaves its base and heads for the fishing grounds. As soon as it arrives on the scheduled grounds, the work commences.

Table 5.--Present fleet of skipjack and tuna boats

(as of Sept. 20, 1949)

Size	<50 ton	50-100 ton	100-150 ton	150-200 ton	200 ton <
Number of vessels	377	572	135	148	4
Percentage	30.5	46.3	10.9	13.4	0.4

Note: From Suisan Jihō, April 1950.

Setting of the lines ordinarily begins before dawn. The lines are thrown from the deck at the stern while the vessel is underway. The joining of the trunk lines, transportation and attachment of bait, the attachment of floats and light buoys, etc., are performed rapidly by a skillful division of labor. When the setting of the scheduled number of baskets of line has been completed, the vessels begin patrolling back along the line. The floats are kept under observation and if there is any catch on the line the fish are brought into the boat. When the number of units of gear set was small, the vessels patrolled the lines several times and ordinarily began hauling lines around sunset. However, at present, when the number of baskets of gear set at one time is extremely large, the time needed for hauling lines is long and there is no opportunity to patrol the lines carefully.

A line-hauler is used to haul the lines. In some cases the line-hauler is powered by electricity, but in other cases it is turned by a belt operated directly off the boat's engine. The machine is of simple construction with two rollers turning in opposite directions. In order to prevent slippage of the line, the rollers are covered with rubber.

The speed at which the line-hauler is run and the speed of the vessel must be adjusted in various ways depending on the condition of the line. The line-haulers in use at present can ordinarily handle 400 to 800 feet per minute. Although the machine does wind in the line, it is not a case of simply hauling the line into the boat by force. When there are fish on the hooks, they must be brought into the boat, and if the line is tangled, the tangles have to be cleared so that the gear will be ready for use the following morning. Consequently it takes over 10 hours to get the line in and it not rarely happens that the work is carried over to the following day. This work is also carried on by a very systematic division of labor.

Working in this fashion from before dawn to midnight with almost no time to rest, living in a small boat with no comforts or recreation, and repeating the same operation 20 or 30 times, the exertions of the men employed in this fishery are by no means commonplace.

Squid, saury, mackerel, and sardines are most commonly employed as bait. Trichiurus has also been used with good results and herring are sometimes used. The fact that live bait is not necessary as it is in the pole and line fishery is an extremely strong point of this fishing method. This fact makes it possible to operate over long periods of time and to develop fishing grounds at great distances. Bait is brought from the base in ice or frozen. At times even salted bait is used. In former times when the number of units of gear fished was smaller, some boats eked out their supply of bait by catching squid on the fishing grounds after hauling the lines. Boats based in Formosa used to employ as bait chiefly milkfish (Chanos chanos), which were raised in ponds. As this fish is cultured widely throughout the southern areas, it offered the possibility of large scale utilization as longline bait in cases where we were able to have bases in the south where bait fish are scarce. Besides the milkfish, the ginkagami (Mene maculata) was used, particularly where spearfishes were the objective of the fishery.

Considerable attention is given to the selection of bait because of the idea that the type of bait will cause variation in the species making up the catch and in the success of the fishing. However, in actuality the effect that the type of bait has on fishing success is not well understood and it cannot be thought that it makes such a very great difference. For example, in the data from investigations of yellowfin grounds in southern waters it is difficult to perceive any noteworthy differences in the catch rate whether squid, frozen sardine, frozen herring, or salted sardines were used. Furthermore, when we examine the stomach contents of tunas and spearfishes, we find that they are quite heterogeneous, the foods which are most abundant in the area of catch or those which are thought to be comparatively easy to capture being predominant. It is considered that these facts indicate that these fishes have a low degree of preference or selectivity with regard to their food.

The suitability of a bait, though of course it varies with the species, is determined by whether it keeps well on the hook, whether it is of a handy size, and whether it will easily catch the eye of the tuna. The matter of the keeping qualities of the bait, of course, means the state of its preservation. As far as ability to catch the eye of the fish is concerned, the optimum condition is probably a bait which is alive and moving about.

It is not known when the longline fishery began nor who started it. It is said however that it has been carried on since quite ancient times. The author has not yet had an opportunity to investigate its history and consequently knows none of the details about it.

The fact that the tunas have borne a deep relationship to the inhabitants of the Japanese archipelago since very ancient times is clearly shown by the fact that tuna bones are often discovered in shell mounds.

We have no way of knowing by what method the tunas were taken in those times. It is very hard to believe, however, that in that period when dug-out canoes were used the people were carrying on a very large scale fishery. It is imagined that the fish were taken by simple hooks, perhaps by some sort of fixed gear along the coast, or by harpooning. As far as the hook and line fisheries are concerned they probably developed on a gradually increasing scale from pole and line or hand line gear to trolling and drift lines, the tuna longline finally being devised as a development from the drift line or the bottom longline.

It has been recorded that longlines of the same type of construction as those in use at present were fished in the Bōsō area well over 200 years ago and that they had considerable success even at that time. The tradition in the Izu region is that the gear was originated by one Fujii in the Kaei Era (1848-53). In any case, considering the size of the fishing boats of that time, it seems certain that the fishery was on a small scale and that the fishing grounds were limited to coastal waters.

From the beginning of the Meiji period (1868) to about the 40th year of the Meiji Era (1907), when engines first began to be employed in fishing boats, the course of development of the fishery as given in the Awa Suisan Shi was generally as follows.

The tuna longline boats used in the Bōsō region before the Meiji period were rarely of greater than 6-foot beam. In the early years of Meiji the boats increased somewhat in size, but even so the maximum was about 6-foot 3 to 4 inches beam. The standard gear in use before the Meiji period had a trunk line of 300 fathoms with 15 branch lines per skate. The amount of gear employed by a boat at one time appears to have been about 5 skates. This would be about 75 hooks. As the years passed the size of the vessels and the number of crew members gradually increased.

Around the 14th and 15th years of the Meiji Era (1881-82) shipbuilding techniques progressed greatly, the size of the vessels gradually increased, and the fishermen began to spend 2 to 3 days at sea on each trip. As the size of the vessels increased, the area of operations also gradually extended.

In the early years of the Meiji period the area of operations did not exceed the distance of 25 miles from the coast, by the 15th year it had been extended to 38 miles, by the 20th year to 50 miles and thereafter until around the 40th year of the Meiji era (1907), it was extended at approximately the rate of 1 ri (2.5 miles) per year until the fishing boats from the Bōsō (Chiba Prefecture) area were active from waters off Chōshi to the coastal waters of the Izu archipelago.

Thus the fishing grounds were extended from year to year, with the small sail- and oar-propelled fishing boats of that time. This extension of the fishing grounds was accompanied by an increase in losses of vessels and a great increase in the number of fishermen lost. For this reason in the Tomisaki area this gear was called the "widow line". This strange name is an expression of the extremely tragic situation in which a large number of young men were lost in this fishery, leaving behind numerous widows. (The foregoing is abstracted from the Awa Suisan Shi.)

In this manner the fishery has advanced step by step, however, the tempo of that advance was by no means fast and in the process a great many lives were lost. In the latter years of the Meiji Era internal combustion engines came to be used as propulsive power in fishing boats, and this brought about a great change which might be called the industrial revolution in this fishery.

It is said that the first man to consider and try the use of a fishing vessel powered by an internal combustion engine was Mr. Bunshichi Maruo of Shizuoka Prefecture. He was not a fisherman but rather was engaged in ocean freight carrying, but in the course of his voyages he had often encountered large schools of skipjack and conceived the idea of attempting to operate a skipjack fishing vessel powered by an engine. Mr. Maruo installed a 5-horsepower engine in a 20-ton Western-style sailing vessel and began fishing for skipjack out of the port of Shimizu. That was in Meiji 36 (1903).

Mr. Maruo's experiment unfortunately ended unsuccessfully, but it provided the motive for the construction of a powered vessel, the Fuji Maru, in 1906 as the Shizuoka Prefecture experimental fishing vessel.

When the Fuji Maru began its work it was the focus of attention in skipjack fishing circles, and as the results of its operations were extremely successful, it provided a strong stimulus to the industry. In view of the success of this vessel, the Shizuoka Prefectural authorities adopted an extremely appropriate and positive subsidization policy with the result that in 1909, only 3 years after the construction of the Fuji Maru, there were actually 150 powered vessels in the Prefecture.

Next the Isuzu Maru was constructed as an experimental vessel by Mie Prefecture. This vessel, too, enjoyed good success and the industrial revolution in this fishery spread throughout the country with the rapidity of a prairie fire.

At that time fishing boats were generally of about 20 tons and 20 horsepower, but thereafter they gradually increased in size until steel vessels of 200 tons and 400 horsepower were built for skipjack and tuna fishing.

At the time when power boats first came into use the fishing grounds were limited to coastal waters, but with the increase in size of the vessels, the navigational techniques of the fishermen were greatly improved, and the radius of operations extended from year to year. In the late years of the Taishō Era (1912-25) boats were fishing from the waters off northeastern Honshū to the Ogasawara and Okinawa islands, and in the early years of the Shōwa Era (1926-)

the so-called Nojimasaki fishing grounds for albacore in the central Pacific were developed. At about the same period fishing vessels from prefectures in western Japan such as Kagoshima, Kōchi, Wakayama, and Mie, led by their prefectural research and exploratory fishing vessels, began to fish in the distant South China Sea, Sulu Sea, and Celebes Sea. After 1936 it gradually became clear that the waters of the former Japanese mandated South Sea islands were excellent yellowfin fishing grounds and large boats based at the port of Misaki in Kanagawa Prefecture began to compete with each other in fishing that region. This condition continued up to the beginning of the war, with the Misaki fleet fishing tuna grounds within an operating radius of about 2,000 miles.

There was also a large number of fishing boats based in Formosa and in the South Sea islands. Those based in Formosa numbered 700 vessels, with a total tonnage of 6,000 tons, and they fished grounds in the waters east of Formosa, in the South China Sea, the Sulu Sea, the Celebes Sea, and the East Philippine Sea, their operating radius extending about 1,000 miles from the port of Takao.

The above figures give the operating radius for single vessel operations, but in mothership-type tuna fishing carried on experimentally from Takao before the war the range was further extended to take in the Banda, Flores, and Timor seas, and the Indian Ocean coast of the Greater and Lesser Sunda archipelagos.

The foregoing are the ranges within which commercial vessels actually fished, but many research vessels and the training ships of the Fisheries Institute surveyed in addition to the areas mentioned above the coastal waters of New Guinea and the Solomons to the south, the coastal waters of Sumatra, the Andaman, and Nicobar islands to the west, and even went as far as the Maldive Archipelago in the middle of the Indian Ocean. Thus the waters in which Japanese actually set their tuna longlines in one way or another cover an extremely broad area from 70° E. longitude to 165° W. longitude and from 15° S. latitude to 45° N. latitude. If to this we add the waters fished by Japanese emigrants in Hawaii and California, it is probably no exaggeration to say that all of the warm seas from the central Indian Ocean east across the whole Pacific have been developed by Japanese or by Americans of Japanese origin. There is probably room for reconsideration and reason for criticism concerning the question of whether or not the measures, methods, and spirit with which this development was undertaken were all that they might have been, but leaving aside that problem, development of these fishing grounds can be expected to make no small contribution to the prosperity of the human race in the future. From this point of view it is truly a great accomplishment which deserves to be writ large on the pages of the world's fisheries history.

As was stated earlier, the tuna longline fishery made a great revolutionary step forward through the application of internal combustion engines to fishing boats. The adoption of the line-hauler, too, was another extremely significant force for the development of this fishery.

It is recorded that the line-hauler was imported from England and first came into use in 1911. The length of the main line of one skate of gear is about 300 meters. As from several score to 300 to 350 skates may be used at one time, it would be absolutely impossible to raise the gear in a short time by the use of manpower. The adoption of the line-hauler can be said to have supplied the solution to this problem of time and labor. In other words the utilization of the internal combustion engine increased the operating radius of the fishing boat and the adoption of the line-hauler remarkably improved the efficiency of the work.

Thus the utilization of machine power was a force which operated for the rapid development of this fishery, and the progress of that development in terms of catch is shown by the following table.

Table 6.--Landings in Japan (from Ministry of Agriculture and Forestry statistics for the tuna longline fishery)

Year	Catch (pounds)	Index
1925	28,578,622	52
1929	49,092,209	81
1930	54,874,940	100
1934	54,062,098	99
1935	47,903,702	87
1936	67,316,014	123
1937	61,071,345	111
1938	69,543,315	127
1939	94,637,530	172
1940	77,750,694	142
1941	51,524,606	94

Note: 1. The index number takes 1930 as 100.
2. The reasons for the decline in 1934 and 1935 are unknown.
3. The sharp drop in the catch in 1941 is assumed to be due to a decrease in the number of vessels fishing because of the war.

The above figures represent only the catch of tunas, but in addition there were 3,000,000 to 4,000,000 pounds of spearfishes and an unknown but large amount of sharks. As for the situation outside of Japan proper, in Formosa the Government-General began investigations in 1913 and continued collecting statistics regularly thereafter. The catch for that region is shown in the following table.

Table 7.--Tuna longline catch in Formosa (Formosan Fishery Statistics, 1936)

Year	Tunas (pounds)	Spearfishes (pounds)	Total (pounds)
1932	6,669,136	7,156,967	13,826,104
1933	6,708,371	7,078,450	13,786,821
1934	7,069,623	9,817,720	16,887,346
1935	6,699,488	9,327,267	16,422,755
1936	11,120,212	8,694,086	19,814,298

Note: (1) Converted from *kin* to pounds at the rate of 1 *kin* = 1.32 pounds.
(2) Figures in this table are not actual values but deduced values, however, their accuracy is rather high.

As I do not have at hand statistics for the years from 1937 on I cannot show the situation in recent years, however, the catch in 1940 appears to have been around 37,215,000 pounds. As will be described later, the catch at Formosan bases had a very high proportion of spearfishes, in many cases over half. In addition the catch of sharks by longlines was around 4,000,000 to 4,500,000 pounds.

With the beginning of investigations by the former South Seas Government-General, the waters of the so-called Inner South Seas area were gradually revealed as superior fishing grounds. From around 1936 on this area was fished by large boats based at the port of Misaki in Kanagawa Prefecture in addition to the boats based within the South Seas. The following table shows the operations and catch of Misaki-based boats.

Table 8.--Number of vessels operating in waters of the South Seas Government-General and their catch (Ministry of Agriculture and Forestry statistics)

Year	Boats (cruises)	Catch (pounds)	Catch per Boat (pounds)
1936	84	4,335,688	51,613
1937	128	8,496,515	66,375
1938	191	7,991,483	41,846
1939	84	5,699,403	67,847

Note: (1) The above figures are the total for tunas and spearfishes but do not include sharks.
(2) About 75 percent of the catch was yellowfin.

With this extension of the fishing grounds the actual number of fishing days gradually decreased in relation to the number of days required for a cruise. In other words, the number of days required to go to and from the fishing grounds increased until it was equal to or greater than the number of days during which fishing was actually carried on. In single vessel operations this sort of situation arises naturally, and in such a situation the overhead expenses naturally rise. Furthermore, as the China Incident gradually became more serious the supply of materials required for the fishery became very uncertain due to preparations for the Pacific war. In particular the strengthening of controls on fuel and strong demands for its conservation made it very difficult for vessels to operate singly in the southern region. The so-called mothership-type tuna fishery was conceived as a device to overcome these difficulties. Within Japan proper its chief proponent was the Kaiyō Gyogyō Kyōkai, which began a campaign to interest all parties concerned.

The plan proposed by the Kaiyō Gyogyō Kyōkai, as can be seen from the following summary, combined the mothership-type operation with advance base facilities and therefore can hardly be called a pure mothership-type operation. However, the plan is presented here for the reader's reference because in these postwar days the necessity of mothership-type tuna fishing is again being strongly urged. Under the completely changed conditions of the present day it need hardly be said that the part of the plan relating to base facilities is out of the question.

Plan for the development of the tuna fishery in the South Sea islands (From Kaiyō Gyogyō, Volume 5, 1940):

The tunas are distributed over an extremely wide range in the South; the stability of their fishing grounds has been in general established by various investigations undertaken in the past. However, because of the distance of these grounds from Japan and the fact that they lie within the tropics, the only exploitation of the area has been the fishing done in the South China Sea, the Sulu Sea, and the Celebes Sea by boats based in Formosa. Boats from Japan hav generally operated in the Pacific Ocean grounds in the vicinity of 180° longitude.

With the recent strengthening of the controls on fuel oil and other materials essentia to the fishery, the vessels operating in the North Pacific have made a 90° turn and have sought fishing grounds in the southern Caroline Islands. Good results were obtained and an increasing number of vessels have continued to fish in this area. In 1938 a total of 39 large vessels made 145 cruises to take a catch valued at 1,560,831 yen. At the same time the researches of the South Seas Government-General Fisheries Experiment Station and surveys carried on by the Nankō Fisheries Company have shown the value of these grounds and the South Sea island grounds have quite suddenly become the center of the tuna fishery.

However, the present type of single vessel operation from Japan still has some disadvantages. As we fortunately have suitable advance bases in the area, it should be profitable to call together the large fishing vessels now operating singly, form them into an organized fleet, and assign to that fleet refrigerated cargo vessels which would carry the catch to Japan. (The rest of the plan is omitted.)

It was planned to use as motherships diesel-powered vessels of 500 tons, each mothership to transport the catch and supply necessary materials for six fishing vessels. It is imagined that the comparison between the income and expenditure of this type of operation and single vessel operation would be as shown in the following table.

Table 9.--Comparative income and expenditures of single vessel and mothership-type operations (plan of the Kaiyō Gyogyō Kyōkai)

Item	Single vessel (yen)	Fleet (yen)	Difference (yen)
Income	3,600,000	5,400,000	1,800,000
Expenditures	2,639,880	3,860,760	1,220,880
Profit	96,120	1,539,240	579,120

Note: (1) Catch per fishing boat per trip 82,700 pounds.
(2) Calculated at the price of 1 yen per kan (8.27 pounds).
(3) The foregoing table is for 6 fleets, a total of 36 fishing boats.
(4) From Kaiyō Gyogyō, Volume 5, 1940.

As was made clear above this plan is not for a pure mothership-type fishery, as it envisages the establishment of an advance base, and the reduction of the overhead expenses of single vessel operations by having the so-called mothership transport the catch and the operating materials for a number of fishing boats. In actuality this scheme never got beyond the planning stage and was never put into operation.

Mothership-type tuna fishing was tested by the late Technician Mokuichi Shimoda in 1932 and 1933. Earlier, beginning in 1930, the Fisheries Institute training vessel Hakuyō Maru had practiced tuna longline fishing in various regions of the South. As the exercises of the Hakuyō Maru could be considered a sort of mothership-type operation, the mothership experiments of Technician Shimoda were probably inspired by the Hakuyō Maru's results.

Technician Shimoda's mothership-type tuna fishing was a system in which the 1,537-ton Haruna Maru was employed as a mothership with two 9.6-meter, 45-horsepower boats and six 7.8-meter, 6-horsepower boats as catchers. The catcher boats were carried aboard the mothership, lowered each time they fished, and brought back aboard when the fishing was finished. As the mothership had refrigeration equipment and canning machinery and the catch was processed aboard the ship, it might be more appropriately called a combination floating cannery and mothership rather than a pure mothership-type vessel.

With this system the Haruna Maru operated experimentally off the Indian Ocean coast of Sumatra, around the Nicobar Islands, and in the vicinity of Timor. On the basis of its results it was concluded that mothership-type tuna fishing offered good possibilities.

However, to cite the weak points of the Haruna Maru's system,

1. A little rough weather makes it difficult to lower and bring aboard the fishing boats.

2. As the fishing boats are small, their activity is greatly limited by the weather.

3. Even in calm weather the fishing boats must always operate within sight of the mothership because they are unable to navigate on their own account.

4. No scouting vessels were employed as they are in the case of a whaling mothership.

Even in the so-called doldrums of low latitude seas the northern and southern monsoons sometimes blow with considerable force. Furthermore, sudden winds accompanied by fierce squalls often spring up making the use of portable catcher boats dangerous and interfering greatly with their operation.

While the practicability of mothership-type tuna fishing was being argued in Japan, an early start was made in Formosa. At the end of 1940 the Tōbu Suisan Company, a subsidiary of the Nippon Suisan Company, with the assistance of the Formosa Government-General, planned such an operation and began to put the plan into execution at the beginning of 1941.

The Tōbu Suisan Company employed as motherships the Ōi Maru and the Kitakami Maru, both of 500 tons, based at Takao. Six catcher boats were assigned to them. As these were fishing vessels of the 60 to 80-ton class, they were of course capable of navigating for themselves. One of the two motherships was on the fishing grounds at all times, directing the fishing fleet and freezing the catch aboard in the form of fillets. A mothership would remain with the catchers on the fishing grounds for about one month, during which time the other mothership was carrying the catch to the base, and loading provisions, fuel, bait, and other necessary materials to be carried to the fishing grounds. On arriving on the fishing grounds, this ship would take over direction of the fleet and the other mothership would head for the base.

When it was attempted to put this system into actual practice, it became painfully obvious that the catcher boats were too small. If they were unable to utilize the lee of an island, the transfer of catch and supplies at sea presented various difficulties and obstacles. The welfare of the catcher boat crews operating at sea over long periods also was probably a major problem.

Several operations were carried on by this method, the fishing being done in the East Philippine Sea, the Celebes Sea, the Banda Sea, the Flores Sea, and the Indian Ocean area. The results were disappointing at first because of unfamiliarity with the fishing grounds but they gradually improved. However, as this enterprise was subsidized by the government and was subject to the influence of the controlled economy of China Incident days, it differed considerably in character from an enterprise in a free economy, and though the results may be of value for reference they cannot be applied in their entirety to present conditions.

At about the same time the Hayashikane Shōten Company planned the same sort of an enterprise using a Formosan base, but this plan was not put into effect and the Tōbu Suisan Company also ceased its operations just before the outbreak of the Pacific War.

The tuna longline fishery, like other high seas fisheries, was forced to cease functioning during the latter half of the war. During that period more than half of the fishing boats were lost. At the end of the war the rebuilding of the fishery was viewed pessimistically, but recovery has proceeded at a surprisingly fast rate and today, 4 years after the end of the war, the number of vessels engaged in the fishery is nearly as high as it was before the war. As reasons for this rapid recovery we may cite the fact that the skipjack and tuna fisheries require less material than other fisheries and therefore were easy to enter in the postwar period of scarcities, the fact that postwar Japanese financial circles took a great interest in fisheries, and the fact that much of the area open to fishing by SCAP was skipjack and tuna grounds while there was little room for the expansion of other fisheries.

We cannot, however, be satisfied with the superficial type of recovery indicated by an increase in the number of fishing vessels. Whatever future developments may bring, we must face directly as a present problem the extremely difficult business conditions in this fishery. In the turbid whirlpool which defeat in the war made of the Japanese fishing industry it is impossible that this fishery alone should attain prosperity while almost all other industries are in difficulties. It may also be thought that this fishery is involved in the general depression in the fishing industry brought about by abnormal oceanographic conditions of recent years. Another factor inhibiting the prosperity of this fishery can be thought to be its lack of planability resulting from its primitive character. However, as the most fundamental factor we must probably take up the problem of fishing grounds. It seems necessary to examine thoroughly the character as fishing grounds of the areas which have been opened to us. It is no exaggeration to say that of the areas in which the Japanese have been permitted to fish, the only ones which have much value as tuna grounds are the albacore grounds of the north central Pacific during the season from November to March and the subtropical spearfish grounds, where the season is May and June.

Concerning such questions as when the day will come when Japan can play an independent role on the international scene and what waters may be opened to Japan at that time I have no answer at all. I only know that the tuna fishery cannot continue as it is at present. It is said that a peace treaty is to be given to us, and that we cannot now ask for anything. However, if it may be permitted to hope, I should wish that all restrictions which might be the cause of useless dispute might be withdrawn from the tuna fisheries, whose grounds are entirely on the high seas. I do not, however, hope for an unconditional withdrawal. A fair agreement for the maintenance of the resource should be made among the countries surrounding the Pacific and Indian oceans and suitable control should be carried on under that agreement. What we should do here in Japan is to strive to become an influential member of the international fisheries organization, the founding of which can be foreseen to come about naturally in the future, by attempting the improvement of the personnel employed in the tuna fishery, by thoroughly respecting any international agreement, and by having persons in the industry and fisheries researchers unite in a basic study of the resource.

C. Harpoon Fishery

The spearfishes are the principal objective of this fishery. However, besides the spearfishes, tunas, sharks, rays, porpoises, sunfish, turtles, and indeed anything of use or value which appears on the surface of the sea may be harpooned in this extremely primitive but heroic fishery.

It is of great interest that a fishery exactly like this one is carried on in the Mediterranean Sea around the island of Sicily. The harpoon fishery of the Mediterranean Sea is very old, its origin being said to go back several centuries before the Christian era. In this region the objective of the fishery is principally the broadbill swordfish. On the fishing boats, a crowsnest is rigged at the top of a tall mast from which a look-out surveys the surrounding waters. When a broadbill is seen swimming on the surface, the boat is headed toward it and the harpoon is thrown as the fish comes within range. It appears that natives of southern regions catch fish with bows and arrows, but I know of no details concerning this fishing method.

There are no complete records of the history of the harpoon fishery in Japan so its details are not clear, but in view of the character of this fishery it is not difficult to imagine that it must have a long history.

The gear consists of a harpoon head, shaft, harpoon line, and leader or sekiyama. As the figure shows (Translator's note: figure 7 is omitted.), a steel shaft is fitted to the tip of an oak pole of 12-15 (usually 15) feet. Sometimes there is a single iron rod but ordinarily there are 3 prongs. On the tip of each of the prongs a harpoon head is fitted.

The harpoon head is of steel and is about 4 inches long. A sharp triangular blade is fixed to its tip. A rod is attached at the center of the wing-like part of the blade which slopes back from the point, and the posterior part of this rod is hollowed out and expanded so that the end of the shaft will fit into it. The back edge of the socket is bent out into an oblique projection. A leader of high quality hemp is attached to the neck of the harpoon head and is connected to the harpoon line with sekiyama.

The boats used in this fishery have a simple observation platform above the bridge, and here a lookout stands and keeps constant watch on the surrounding water. Boats which engage in this fishery only part-time do not usually have such a lookout platform. At the bow there is a platform called the pulpit, and it is here that the harpooner stands. On boats which specialize in this type of fishing, the pulpit is large and can accommodate 2 harpooners at a time.

Spearfishes have the habit of swimming with the upper lobe of the caudal fin protruding from the surface of the water. Sometimes a portion of the dorsal fin also protrudes from the water. Fish swimming in this manner can be seen at all times, but it is said that they are particularly numerous in cases where the wind and the current are running in opposite directions causing waves on the surface. It appears that this phenomenon is also often seen during spawning when the fish are chasing each other.

In Japanese coastal waters the fishing season is from April to September. The Hyūga Nada, and the waters off Kishū, Izu, and the Bōsō Peninsula are famous fishing grounds. The coastal waters of eastern and northeastern Formosa are also famous as a fishing ground for this fishery with 14-15,000 spearfishes of various species being taken. The fishing season is from October to April, during the northeast monsoon. White marlin are most numerous, making up 40-50 percent of the total catch.

When the lookout sights a spearfish, the boats give chase at full speed. Arriving within range, the harpooner in the pulpit throws the harpoon. If a hit is scored, the harpoon head comes off the shaft and remains in the body of the spearfish, which is then hauled in by hand by means of the harpoon line.

II. Characteristics of the Tuna Longline Fishery

It is probably no great mistake to consider that the character of a fishery is determined by the character of the resource which is its object, and that the character of the resource is determined by the species which compose it and their environmental conditions. Consequently, if it is possible to reveal and grasp the biological characteristics of the species whic is the object of the fishery and the environmental factors which control the occurrence, progagation, and migration of that species, the character of the fishery can thereby be analyzed.

As was stated earlier, there are a number of different fisheries which have the tunas as their objective, but among them the longline fishery is the most important both in terms of the scale on which it is prosecuted and in terms of the catch. I shall, therefore, take up the longline fishery as a representative of the tuna fisheries and shall give some consideration to its character. The number of species of tunas, spearfishes, and sharks which are the principal catch of the tuna longline fishery is, as will be detailed later, rather great. The majority of them are, from the biological point of view, distributed throughout the open sea from the Equator to the vicinity of 35° - 40° N. latitude. The distribution in the Southern Hemisphere is not yet well known, but it appears that the species are distributed to latitudes about as high as those at which they occur in the Northern Hemisphere. The species have this extremely extensive range of occurrence, however, the density of their occurrence is not the same everywhere within this range, being subject to great fluctuations seasonally and presenting differences in the location of the center of distribution of the various species. In other words, in different regions of the sea the composition of the catch is different, and seasonal changes give rise to other variations.

Put in very broad terms, the differences in the density of occurrence of the majority of the species making up the resource of the tuna fishery appear to be mainly related to latitude. This probably indicates that among the environmental factors which control the distribution of these fishes, temperature is a great limiting condition. The foregoing, of course, only states a general tendency and there are cases in which some species show a marked trend toward variations in an east-west direction. In other cases it is thought that the density of distribution is affected by topographical conditions. In still other cases, changes in the density of distribution from one region to another appear to accompany growth. However, an extremely broad range of occurrence, a high degree of mobility of the fish, and migrations extending over broad areas of the sea are common characteristics of these species which make up the resource of the tuna fishery, giving them a very different character from the resources of the coastal fisheries or the bottom fisheries.

The information which we have been able to gather concerning the spawning and growth of these fishes is as yet extremely poor. Among the fishes taken by the tuna fishery, the sharks are viviparous and therefore are already possessed of fairly strong powers of survival at the time they leave their mothers' body. The tunas and spearfishes are oviparous and for sometime after hatching they have extremely poor powers of resistance. In the case of the sharks, if we know the number of times they produce young in one year and the number of young produced at one time, it is possible to clarify the question of their reproductive potential comparatively easily. In the case of the oviparous tunas and spearfishes, however, even though we may be able to calculate the number of eggs contained in a matured ovary, we cannot easily ascertain the proportion of those eggs that are fertilized and hatched. Furthermore, judging from the fact that the larval and juvenile fish are extremely weak, it is not difficult to imagine that attrition during the early stages of their life is at a rather high rate. In actuality it is by no means rare to find tunas and spearfishes of 10 to 40 cm. in length among the stomach contents of adult fishes of the same species. From our present knowledge of several species, it appears that the number of eggs spawned at one time by these species may range from several hundred thousand to several million, but it is difficult to believe that very many of these eggs grow into mature individuals, and the attrition accompanying growth is probably rather drastic.

In the viviparous fishes like the sharks variations in reproductive potential from year to year are probably comparatively small. We do not know much as yet about the number of times the young are produced each year, but the number of young sharks produced each time varies greatly with the species, being always two in the case of thresher sharks, less than 10 in the case of mako sharks, and from 10 to 40 in the case of great blue sharks. In the case of the oviparous tunas and spearfishes, it can be imagined that the effect of environmental conditions is very great and that fluctuations in reproductive power from year to year are marked. In other words, the number of eggs spawned is enormous and therefore even slight variations in environmental factors will be reflected on a large scale in the total stock through their action on fertilization, hatching, and growth.

The spawning habits of the tunas and spearfishes are not yet well known, but the degree of maturity of various individuals in a single school is extremely variable, the distribution of sexually mature individuals is extremely extensive, and it appears that the occurrence of juvenile fish is also remarkably broad but very sparse so that they cannot be collected in large numbers. Furthermore, juvenile fish of various sizes can be taken in the same area at the same season, and it is thought that all of these phenomena indicate that it is the habit of these fishes to spawn over a wide area throughout a rather long period of time.

When we consider the oceanographic characteristics of the low latitude seas which are the spawning grounds of these fishes, we see that the content of nutrient salts in the sea water is small and that it varies little throughout the year. This means that the quantitative distribution of plankton is small and that its seasonal variation is also small. Accordingly, it may be thought that the food for juvenile tunas and spearfishes is not very abundant and that the seasonal changes in its quantity are not very pronounced. Such characteristics are markedly different from those of the waters of high latitudes. In the seas of high latitudes we find seasons of conspicuous proliferation of plankton accompanying changes in temperature. In coastal waters nutrient salts are constantly supplied from the land by rivers and by other agents. However, in the very middle of the ocean there is no source of supply for these nutrient salts. Consequently, in the seas of the low latitudes where these fishes spawn and pass their juvenile stages, the conditions are like those in overworked soil with an insufficient supply of fertilizer. It is thought that the reason that the spawning of tunas and spearfishes in such waters extends over such a broad area and such a long period of time is that this is the most reasonable way of attaining the objective of maintaining the species. In short, spawning over a broad area and throughout a long period is in better agreement with the environmental conditions in the seas in which these fishes spawn, from the point of view of the maintenance of the race, than would be spawning in a comparatively restricted area and a short period of time, as is the case with fishes of the high latitudes.

No connected study of the food habits of the tunas and spearfishes has been made and they are not well understood. There is no room for doubt that their food in the juvenile stages consists of various kinds of plankton. The natural food of the adult is indeed heterogenous, and it is very doubtful whether they exercise a great deal of selection with regard to their food. It is thought rather that they eat whatever is most abundant in the area where they occur or whatever is comparatively easy to catch. The spearfishes and sharks eat mainly large fish and squid. The tunas eat, in addition various kinds of large plankton. The plankton feeding character seems to be most pronounced in the albacore. At some places and seasons Alepisaurus, deepsea fishes, and fishes such as Bentenia, which are thought of as rare species, are very commonly found in their stomachs.

If we take all of these factors into consideration, we may think that the resource of the tuna longline fishery is propagated and maintained throughout an extremely broad expanse of ocean. If we consider this resource in terms of the sea which supports it, the density of distribution expressed as fish per unit of area can naturally be thought to be rather low in comparison with the resources of the coastal fisheries or of the fisheries in northern waters. However, as regards the absolute quantity of the resource, we cannot conclude that they are necessarily inferior to other fisheries resources, if we consider the area of the seas in which they occur.

The fact that the density of distribution of the resource is low in terms of fish per unit of area is not an advantageous condition from the standpoint of the fishery. If the tunas and spearfishes led a sedentary existence with a low density of distribution, they would be difficult to catch and they would have an entirely different significance as the objectives of a fishery. However, they do not live in this way, but rather form schools and migrate and the fishery is established by utilizing this migratory character. Furthermore, the location and nature of the fishing grounds and fishing seasons are naturally determined by these migrations. Unfortunately our knowledge concerning this migratory character is as yet extremely inadequate, and we canno utilize this characteristic fully, this being the greatest reason for the lack of stability in the tuna longline fishery. The number of species which make up the resource of the tuna fishery is rathe large. We have not yet reached any solution to the problem of whether each of these species is a single stock or whether there are a number of independent stocks in the Pacific and Indian oceans.

There are some people who think that each of these species which is distributed throughout the whole Pacific Ocean is a single stock and that at some time in their lives all of the fish of each species migrate into Japanese waters. The migrations into Japanese waters occur each year at about the same season and are made up of fish of about the same size each year. Considering only these facts, it may be thought that this theory is correct. However, when we consider the extent of the Pacific Ocean, there are some facts which give rise to doubts concerning the above opinion and we know of some phenomena which can be thought to indicate the existence of distinct races.

The solutions to all of these problems must await future research, but they are problems which must be solved in order to determine the character of the resource.

Dr. Tauchi[2] has studied the effects of fishery on the stock and has reported that the catch rate for the tunas in Japanese waters ranges from 10 to 55 percent[3], varying with the species and among various age groups within a species. In every case he gives rather high values. However, as was mentioned earlier, there is doubt as to whether or not all of the tunas necessarily at some time in their life migrate into Japanese waters, and therefore even though Dr. Tauchi's values may correctly show the catch rate in Japanese waters, it is naturally doubtful whether the tunas of the whole Pacific are being caught at catch rates like those cited above.

If we consider the relationship between fishing effort and catch in the past, based on statistics of the Ministry of Agriculture and Forestry, the Colonial Office, and the Formosa Fisheries Experiment Station, we cannot perceive any very clear correlation. It appears that a tendency toward an increase in the catch with an increase in fishing effort can be detected, but we can see conspicuous fluctuations in the amounts of the catch from year to year.

Statistics showing fishing effort are almost entirely limited to the number of vessels engaged in the fishery and their total tonnage and therefore the fishing effort is shown by deduced values which do not make very good data. Figure 8 shows the total catch, the number of vessels engaged, and the total tonnage of the vessels for the period from 1930 to 1940. The graph shows index figures with 1930 as 100. It can be seen from the figure that the increase in the size of the fishing vessels from 1934 on was very conspicuous.

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[2] Tauchi, Morisaburo. 1940. Bull. Jap. Soc. Sci. Fish., Vol. 9, No. 4, pp. 133-135, 136-138, 139-141.

[3] Catch rates here mean the proportion of the stock represented by the total catch.

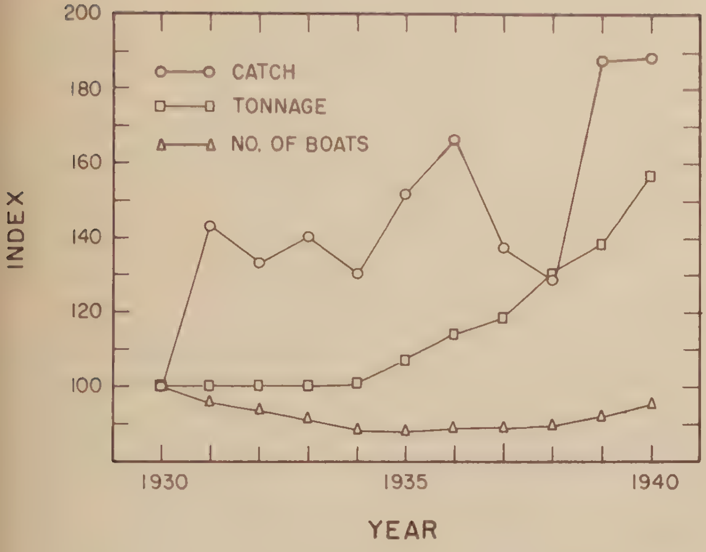

Figure 8. --Catch in relation to number of boats and total tonnage of vessels.

It is considered that both increases and decreases in the number of operating vessels and changes in the size of the vessels show increases or decreases in the fishing effort. It is not, however, reasonable to consider these simply as increases or decreases in the fishing effort applied to the same resource. The reason for this is that in many cases an increase in the size of the vessel means an extension of the operating area to more distant fishing grounds and with the change in fishing grounds there is a great possibility that different kinds of fish will be taken. Furthermore, it may also be thought that a shift to more distant fishing grounds will result in a reduced number of operations in the course of a year so that in some cases at least larger vessels do not mean an increase in fishing effort. Consequently this comparison of the total catch of the tunas with the number of boats and their total tonnage does not enable us to discuss the correlation between fishing effort and the stock.

These factors must nevertheless be thoroughly considered. In figure 8 we can see fluctuations of about 10 percent in the number of vessels, and from 1934 on the total tonnage increased sharply. Wide variations from year to year in the total catch can be seen, but through these variations is shown a tendency for the catch to rise. It should be noted that the catch shown here is a total of tunas and spearfishes and does not show any particular species. At any rate, even though some degree of correlation can be detected between the total catch and fishing effort, it may be thought that there are some other factors operating outside this correlation to bring about fluctuations in the catch. The most important of these factors are thought to be changes in the migrational pattern accompanying changes in oceanographic conditions and variations in the recruitment to the stock caused by changes in environmental factors. In any case there is something which operates independently of fishing effort to control the variations in the catch, and if the effect of fishing effort on the increase or decrease of the stock can be ignored, it cannot be thought that this condition implies overfishing.

Overfishing means that the catch exceeds the natural increase of the stock. Deciding whether or not a particular stock is being overfished is an extremely difficult problem. As far as the resources of the tuna longline fishery are concerned, up to this stage in their development no one has put forward any definite views as to whether or not they are being overfished.

The danger that the fisheries resource may be overexploited arises from the relationship between the reproductive potential and area of distribution of the resource and the effectiveness of the fishing. In fishes which have a high reproductive potential, there is comparatively little danger of overfishing. The same is true of fishes which have an extremely broad range of occurrence. However, where the fishing is extremely efficient and effective, it may naturally be thought that there is danger of its outweighing such considerations as the reproductive potential.

Except in some special cases, net fishing has not become established in the tuna fisheries. The longline fishery is the nucleus of the fishery. The great majority of the fish taken by longlines are already mature. The fishing implement is a hook, and the manner of its use traces across the open sea a broken rather than a solid line. Consequently, there is almost no danger of cleaning up a school of fish with one set, as happens in net fisheries. It is more reasonable rather, at least under present conditions, to think of it as a kind of thinning out. As yet no one has expressed a definite opinion as to whether or not the resources of the tuna longline fishery are being overfished. This can be thought to mean that there are no data with which to arrive at a definite opinion.

To sum up the foregoing, it is considered that the resources of the tuna longline fishery are of such character that there is little danger of their being overfished, judging both from the conditions under which they are propagated and maintained and from the type of gear and the fishing method used. In short, the effect of man's effort on the resource is really very slight when compared with the effect of natural conditions. This means, on the other hand, that this fishery is lacking in planability and stability and this is the reason why it is one of the most primitive in character of all fisheries.

III. General Outline of Fishing Grounds and Fishing Seasons

The longline fishery for tuna has developed in very close association with the pole and line live-bait fishery for skipjack. The majority of the boats in this fishery fish for skipjack approximately half of the year, including the summer season, and engage in the longline fishery during approximately half the year, including the winter season. This manner of operation, in general, is connected with the prospects for profit to the operators. As was stated earlier, the vessels which engage only in this fishery, taking no part in skipjack fishing at any time of the year, now amount to 25 percent of all skipjack and tuna vessels. Furthermore, in areas where the geographical distribution of the fishes makes longline fishing profitable, the boats engage in longlining even during the summer season. The longline fishery for spearfishes on the grounds west of Kyūshū is an example, although in recent years the catch has dropped to nothing and the fishery has been abandoned, and the fishery for black tuna off northeastern Honshū and Hokkaidō is a good example as the fishing season is chiefly during the summer.

The tunas and spearfishes are basically warm-water fishes. A short account of their species will be given in the next chapter, but the number of species is rather large and they differ among themselves as regards the areas around which their distributions center, and they differ too in the seasons and routes by which they migrate into Japanese waters.

The black tuna is the most resistant to low temperature of all the tunas, migrating as far as Hokkaido and the coast of Sakhalin, where it is found in waters as cold as 5° C. This is, however, rather exceptional, and in Japanese waters this species is taken in the greatest numbers in water having temperatures of 14° - 15° C. to 20° C. As far as is known at present the warmest waters in which this species occurs are off the Philippines, where temperatures reach 26° to 29° C. This is the southern limit of their distribution in the North Pacific Ocean. This species has the characteristic of penetrating into coastal waters and occurs in the Japan Sea. There are records of their having been taken by fixed gear from Kyūshū to southern Hokkaidō and on the Japan Sea coast of Sakhalin.

The albacore is said to occur in areas having water temperatures of 17° to 26° or 27° C. The northern and southern limits of its distribution extend from the Equator to past 40° N. latitude. In Japanese waters they are most abundant in areas where the water temperature is around 20° C. and generally occur only in offshore waters, seldom appearing in the coastal areas.

For a tuna the bigeye has a peculiar pattern of distribution. It shows little change in density with changes in latitude, but appears to be evenly and sparsely distributed all over its range. Like the albacore it does not appear to enter the coastal waters and tends to become more numerous as one goes offshore. It is said that the level at which it swims differs from day to night and that it shows a conspicuous tendency to swim at deep levels during the day and to appear at the surface during the night.

Among the tunas the yellowfin is the one which most belongs to the waters of the low latitudes, its density of distribution being high in an area centered along the Equator. At some seasons it appears also in the waters of rather high latitudes, but these seasons are short. In general it lives offshore, but it also enters enclosed bodies of water. It is taken, although rarely, in the Japan Sea. As a young fish, when it is called kimeji, it enters the coastal waters and is not rarely taken in fixed gear.

Differences in the distribution of the various species of spearfishes can also be detected. Excepting the broadbill, it appears that the other species on the whole prefer higher temperatures than do the tunas, and the greater part of the catch is made in water temperatures of 20° - 28° C. Except for the broadbill, all the other species in general appear to have more or less of a tendency to be more abundant in coastal water areas, so that the catch seems to be greater in the vicinity of islands. The broadbill has a wide range of distribution, and in Japanese waters its catch pattern to some extent resembles that of the albacore. However, it is scarce in the very far offshore areas frequented by the albacore. In the white marlin and the sailfish the the coastal character is particularly strong and they are most abundant from the 100 fathom line of the continental shelf to Taiwan and the shores of the Philippines. The striped marlin is most abundant in the subtropical central Pacific and its distribution extends to the vicinity of 40° N. latitude. The black marlin is abundant in the Equatorial Countercurrent and the North Equatorial Current. It migrates to the north, but its range of distribution appears to be more restricted to warm seas than that of the striped marlin.

As stated above, the distributional pattern of these species appears to vary mainly from north to south. This phenomenon is thought to indicate that temperature bears an important relationship to the distribution of these fishes. Nevertheless, the range of temperatures which these fish can withstand is, as indicated above, rather broad. In the past these fish were taken as representative of the so-called stenothermal fishes, however, they can be thought of as not necessarily stenothermal but as rather eurythermal.

As has already been said, temperature bears a very important relationship to the distribution and migration of these fishes. However, the range of temperature change which they can endure is rather great and in sea areas which are within that range there is a possibility solely from the standpoint of temperature of the occurrence of these fishes. Water temperatures which limit the possibility of occurrence of these species can become a controlling factor as regards fishing grounds and fishing seasons, but in waters where the temperatures are favorable for their occurrence at all times we can hardly think that temperature has a controlling influence on the establishment of fishing seasons and fishing grounds. It goes without saying that the resources of the oceans are in the last analysis controlled by the chemical characteristics of their waters and the energy of the sun. But it need hardly be said that these fishes, which are living things, have the instinct for self-preservation and the instinct for the preservation of the species, and they act in accordance with these objectives. Studies in this field have advanced so extremely little that we unfortunately have no data on which to base a discussion of the relationship between the distribution and migrations of the tunas and their ecology and physiology.

When it comes to the problem of fishing grounds, the biological distribution and the potentiality of distribution are naturally different. In order that a body of water may have significance as a fishing ground, it is essential that fishing operations be actually carried on in those waters and that the catch be at least such as to pay the expenses of the fishermen.

As has already been said several times, although the centers of distribution of these fishes vary somewhat, they are essentially warm-water animals and consequently most of them occur at all times in the waters of the low latitudes. In the case of the black tuna, the albacore, and the broadbill it appears that the center of their distribution lies in rather high latitudes. In any case, none of these species leads a sedentary life within a narrow area of the sea, but they all move through extremely broad reaches of the ocean. The fishing grounds and fishing season change in response to these movements.

Looking at the situation in Japanese waters, we see that from spring to summer the Japan Current (Kuroshio) increases in strength, so that warm sea water is brought far to the northward, at the same time all of the seas of the northern hemisphere grow warmer, and the tunas and spearfishes gradually move toward the north. The reverse occurs from autumn to winter, when the temperatures in the northern hemisphere gradually fall, accompanied by a return to the south on the part of the fish. The outlines of these movements will be set forth below but in recent years the patterns of migration have undergone much change, the black tuna, for example, scarcely appearing in the coastal waters of Japan and no mass migrations of this species being seen at all.

In the waters of Hokkaidō the black tuna generally appears in July. At about that time the area 20 - 40 miles south southwest of Erimozaki becomes a good fishing ground. By September the schools are usually densely congregated within 30 to 40 miles of the coast from south of Kushiro to Erimozaki. In October all of the offshore waters between Erimozaki and Ezanmisaki are fishing grounds, but from this month on the fish finally begin to disappear from this area. Thus the fishing season on the Hokkaidō coastal ground is from July to October, but in recent years there has been hardly any catch. The longline catches in this area are almost entirely composed of black tuna, other tunas and spearfishes being almost completely absent from the catch and only a few sharks being taken.

In the offshore waters from Iwate Prefecture to Fukushima Prefecture, the so-called Sanriku region, the fishing season is longer than in the Hokkaidō coastal areas. In some years black tuna are taken as early as April, but the season of greatest catch is the 3 months from June to August. Thereafter the fish gradually disappear, but around November they again begin to be caught and scattered catches are made until around January. The fish taken from June to August are called "ascending fish," while those taken after November are called "descending" or "returning fish." In these waters striped marlin are taken in fairly large numbers during the summer and broadbill are numerous in the winter. In some years bigeye tuna are also abundant. Furthermore, during two seasons, in the summer and winter. an extremely large number of *rakudazame* (*Isurus nasus*) are taken by the so-called *mōkanawa* longline fishery.

Off the east coast from Ibaraki Prefecture to Chiba Prefecture, black tuna, bigeye tuna, albacore, and broadbill begin to be taken around November and catches continue to be made until around April of the following year. In the summer the composition of the catch changes, the striped marlin and black marlin increase, and at the same time quite a few yellowfin are taken.

Farther to the southwest in the waters from the Izu Peninsula to the Izu Shichitō islands black tuna begin to be taken around November, the season at which they are caught most abundantly being from January to February. In some years scattered catches are also made in April and May. Bigeye tuna are also taken at about the same time, but their fishing season begins about a month earlier and lasts about a month longer than that for the black tuna. It appears that albacore begin to be taken in some numbers on the longlines around March to May. In early years the yellowfin begin to appear around April and are taken in greater or lesser amounts until November. Striped marlin occur almost throughout the year, but they are most abundant from June to September and are mainly taken with the harpoon. The fishing season for black marlin appears to begin about 1 month later than that for striped marlin. The broadbill are most abundant in the winter, the season being centered around January and February, with the center of their fishing grounds lying to the east of the Shichitō islands.

Farther west in the waters off the Kii Peninsula the yellowfin and bigeye tuna are rather abundant and albacore are taken in some numbers from September to November. From December on the yellowfin and bigeye gradually begin to decline, while on the other hand the albacore catch gradually increases. The albacore fishery is quite active from December to March. The catch situation for the spearfishes is not greatly different from that in the Izu Shichitō region except that in this area broadbill are hardly taken at all. Black tuna are caught sporadically from December to March. A little to the southward on the so-called Kinan Reef fishing grounds centered around 28° to 30° N., 135° E., the albacore fishing is very active in the period from January to March, and at the same time bigeye tuna are fairly abundant and spearfishes and yellowfin are also mixed in the catch to some extent.

Farther to the west in the waters off Tosa (southern Shikoku) yellowfin are taken in rather large numbers from October to December, while the bigeye catch shows more or less of a tendency to increase in January and February. In March and April the albacore catch is large, the fishing grounds lying rather close along the shore.

The so-called Satsunan area (south of Kyūshū) has been a famous black tuna ground since ancient times. As was stated earlier, in recent years there has been hardly any migration of black tuna into this region and consequently there has been no catch. At present the only catch is some bigeye tuna which are taken in the winter. The good fishing grounds for black tuna in general were from 30° - 32° N. latitude, 130°- 132° E. longitude. Formerly, when the black tuna fishery was flourishing, the catch gradually increased from about the middle of December and reached its peak from January to the latter part of February, in some years extending to the first part of March. At this season the port of Aburatsu in Miyazaki Prefecture was bustling with a large number of boats from other prefectures. After the first or middle part of March the catch declined rather abruptly and ordinarily the fishing was completely ended by the latter part of April or the early part of May. As will be related in a later section (V. Fishing Grounds, 11. Nankai Sea Area), the black tuna catch in this area declined abruptly after 1940 and from 1945 on there has been no catch at all. Different people give different explanations for this phenomenon, but it should be noted well that it parallels perfectly the decline in the catch of sardines. No quick decision can be made as to whether it is a falling off of the catch caused by a cyclical decline in the black tuna stock accompanying changes in oceanographic conditions, or whether the fishing grounds have deteriorated because the black tuna changed the course of their food-seeking migration after the sardines ceased to congregate for spawning in this region. Yellowfin are usually slightly more abundant around October and the bigeye show approximately the same pattern, but these species do not present such a clearly defined fishing season as did the black tuna. The albacore catch in this region is extremely small.

The waters to the west of this region from the west coast of Kyūshū to Saishūtō (Quelpart Island) are famous as a fishing ground for the spearfishes. Around March to May some of the black tuna which enter the Japan Sea with the Tsushima Current are also taken there. The spearfish season begins in July to September in the Saishūtō (Quelpart Island) area and the fishery gradually moves southward with the progress of the season. The positions of the fishing grounds generally lie along the 100-fathom line of the continental shelf. Almost all of the tuna taken in the Japan Sea are black tuna. There are extremely rare reports of yellowfin being taken there. The Tsushima Current, which branches off from the main Kuroshio south of Kyūshū, passes through the Tsushima Strait and then flows north along the Japanese coast, while on the continental side there is a southward flowing cold current. For this reason the fishing grounds for the black tuna are naturally limited to the Japan coast and they are only extremely rarely taken along the Korean or Siberian coasts. During the summer the schools gradually move northward and in years when the warm current is very strong they sometimes pass along the west coast of Hokkaido to be taken on the coasts of Sakhalin. In the Japan Sea area there is no longline fishery at all, the tuna being taken entirely with fixed gear.

The central part of the Pacific Ocean eastward from 150° E. longitude and south from 40° to about 26° N. latitude is famous as an albacore ground. In this area most of the catch is made in the northern portion around October, but the center of the fishing grounds gradually moves southward until in the latter part of March it is at around 26° to 28° N. The fishing season in this region ends from around the end of March to the early part of April. The various fishing grounds centered respectively at 160° E. longitude, 175° E. longitude, and 175° W. longitude all differ more or less in their characteristics, but data are scarce and a thorough analysis is impossible. Besides albacore, bigeye tuna are taken rather plentifully, particularly around December. Striped marlin and broadbill are also taken in some numbers, and throughout the seasons scattered catches of black tuna and yellowfin are made.

In the coastal waters of the Ogasawara chain some fish are caught throughout the year. Chief among the tunas taken are the yellowfin and the bigeye tuna. The black tuna is also taken, although very rarely, in the northern part of this sea region around May and June. The albacore catch increases somewhat from March to May. Skipjack boats which operate in this area take albacore on pole and line at about that season. The season of greatest abundance for yellowfin is from May to July and there is another increase in the catch around November. A tendency for the rise and decline in the bigeye catch to be about 1 to 2 months later than that for the yellowfin can be discerned. The most important fish in this region are the spearfishes. Among them the striped marlin catch in general rises and declines at about the same times as the yellowfin, but the increase in the yellowfin catch in November is not paralleled by a similar increase in the striped marlin catch. The rise and fall of the black tuna catch roughly parallels that of the bigeye. Broadbill are rather abundant in the northeastern portion of this sea area, the season being centered around February. In addition there is also a very large shark catch which is chiefly great blue shark.

In the Okinawa region, too, fishing proceeds throughout the year. In this region schools of black tuna appear everywhere from April to June. These schools are thought to differ in age from the previously mentioned schools of the Satsunan Sea area. Yellowfin are rather abundant along the eastern boundary of the Kuroshio and spearfishes are plentiful from the western boundary of the current to the 100-fathom line of the East China Sea. The spearfish catch begins to increase gradually around March and the fishing grounds gradually move northward. At the beginning of the season white marlin are most numerous, followed by striped marlin, after which comes the season for black marlin and sailfish. On the whole the seasonal changes in the catch of these fishes closely resemble the pattern seen in coastal waters of the Ogasawara Islands.

Spearfishes are extremely abundant east of Formosa where the harpoon fishery is very active from October to April, that is, during the season of northeasterly winds. The fishing grounds are within 30 miles of the coast. At the same season in the same areas there is a flourishing longline fishery for sharks, mainly species of Carcharhinus and hammerheads. From April to June the black tuna migrate into these waters and at the same season sailfish are abundant.

In the South China Sea the most numerous species is the yellowfin, its fishing season being the season of northeasterly winds. From March to the early part of June albacore fishing is active from the Bashi Strait to the northeastern part of this sea area. Black marlin and sailfish become abundant from June to August. Albacore are rather plentiful around March in the northeastern part of the sea area.

Black marlin and yellowfin tuna are densely distributed in the waters 60 to 200 miles east of the Philippines during the season of southwesterly winds, the former being more abundant in the north while the latter is more numerous in the southern part of the area. Fishing for black tuna is very active from March to June in waters comparatively close to the coast of northeastern Luzon.

In the Sulu Sea yellowfin are most numerous followed by the spearfishes, and fishing proceeds throughout the year. The Celebes Sea is also an excellent fishing ground with yellowfin tuna most numerous, followed by the spearfishes, of which the chief is the white marlin. The fish are caught there throughout the year, but the peak of the season is during the season of southwesterly winds, the fishing situation appearing to resemble that of the southern portion of the East Philippine Sea.

In the low latitudes of the Pacific, in the grounds centered along the Equator, yellowfin are very abundant, forming about 75 percent of the catch (excepting sharks). Bigeye tuna are about 10 percent and spearfishes about 15 percent. Some albacore are taken, but there are absolutely no records of black tuna being caught there.[4] Seasonal changes in the fishing situation are slight, but in general catch rates are better during the season of southwesterlies than during the season of northeasterly winds. Proceeding northward from the vicinity of the Equator the catch rates for yellowfin fall off sharply, the catch rate curve dipping to a low in the vicinity of 10° N. The spearfishes are most abundant in an area centered on 20° N. latitude.

The preceding is an outline of the fishing seasons and fishing grounds in the western part of the Pacific Ocean north of the Equator. In general the density of distribution of these fishes in this area increases during the summer. However, the albacore and broadbill are more abundant during the winter. From a geographical point of view, the yellowfin are very densely distributed in the Equatorial Countercurrent, spearfishes are most abundant in the North Equatorial Current, and albacore are most plentiful to the north of the subtropical convergence. Broadbill are also more numerous north of the subtropical convergence, but there the principal zone of distribution is narrow in an east-west direction. Bigeye tuna are caught in roughly equal abundance all over the whole area. The black tuna appears to occur chiefly in the area of the Kuroshio.

IV. Fishes Taken by Tuna Longline Fishery

The tunas are among the fishes with which the Japanese are best acquainted, but this is only true of tuna which has been made into sliced raw fish or served on top of rice balls. There are actually few people who know what the fish look like, and even fewer who can tell one species from another. Still fewer people know where and by what methods such fish are taken.

As indicated by the number of names cited in the preceding chapter, the number of species is fairly large. They all migrate extensively in the open sea and their capture is attended by extremely hard labor on the part of the fishermen, who sail the broad sea in small vessels and do battle with the elements.

As has been stated previously, the greatest among the tuna fisheries is the longline fishery. The principal objects of this fishery are of course the various species of tuna, but at some times and places the spearfishes also have an extremely important significance. Although they do not have the economic value of the other fishes, the sharks are also important in the catch of this fishery. The following is a brief account of the habits and form of these fishes.

4/ The capture of a few individuals was reported from mothership-type operations carried on from June to September 1950.

A. Tunas

These fishes all belong to the family Thunnidae, and are very closely related to the mackerels and bonitos.

The body is almost perfectly spindle-shaped and is adapted to swimming at high speed. The root of the tail (caudal peduncle) is extraordinarily slender and is broader than it is deep. This form is well-adapted to a violent, side to side motion of the tail fin. The tail fin is large and strong. As the majority of these fishes are essentially warm-water fish, they are most numerous in warm seas, and they characteristically make large-scale migrations along warm currents. A very great number of species has been reported from the seas of the world, but in actuality it is doubtful whether the number of species is so large. Even though the species may be numerous, they do not after all have any great concern for us, so only the five species which occur in Japanese waters will be described here.

1. Black tuna, Thunnus orientalis (Schlegel)

Bluefin tuna (America).

Depending on the locality and the size of the fish, this species has many names, such as, maguro, kuromaguro, kuroshibi, mejimaguro, yokowa, kakinotane. This is the largest species in the family Thunnidae, attaining a length of 2.5 meters and a weight of 300 to 350 kilograms.

The species is characterized by short pectoral fins, the tips of which do not reach to below the middle of the first dorsal fin. They can easily be distinguished from the other species by this character alone. The back is a light black and the sides are greyish white. The finlets (the disconnected small fins) behind the dorsal and anal fins are yellowish on the back and silvery white on the belly. There are very similar fish on the American side of the Pacific and in the Australian area and by some scholars they are considered to be the same species, but it is said that the dorsal finlets are blue, a characteristic which is indicated by the name bluefin.

The flesh is dark red with something of a blackish tinge. The flesh of the belly contains a great deal of fat, causing its color to vary in different parts from the white-spotted so-called "middle belly meat" to the almost pure white "great belly meat." This part of the flesh is prized as material for sliced raw fish and rice balls garnished with fish. This species is delicious during the winter, but fish taken in the summer are poor eating, except for the small specimens. This is related to the spawning season of these fish, the fish being fat and well-flavored before spawning but lean and tasteless immediately after spawning. It is said that they spawn in Japanese waters around June and July. The fish taken during the summer from the waters off northeastern Japan and the coast of Hokkaidō are fish that have already spawned. These are called Sendai tuna and are regarded as inferior fish.

This species can withstand low temperatures better than any of the other tunas, and because it has the characteristic of coming comparatively close into shore, it is taken with stationary gear. As far as is known at present, the southern limit of its distribution is in the vicinity of 15° N. latitude on the east coast of the island of Luzon. It is not clear whether it occurs farther to the south, but it is thought that its range probably extends south of the Equator. Until recent years it was believed that the southern limit of the distribution of this species was in the vicinity of 30° N. latitude, however, this fish began to be taken in Formosa in 1935 and before the war its annual production there reached a value of 1,500,000 yen. The northern limit of distribution is around 45° N. latitude. In the western Pacific during the winter there are some catches of this species over an extensive area from east to west in the vicinity of 30° N. latitude. Before the war splendid catches were made in January and February to the south of Kyūshū, but this fishery has completely died out in recent years. The schools which appear to the south of Kyūshū moved to the northeast as it grew warmer, and a part of them followed the Tsushima Current into the Sea of Japan.

These fish are frequently seen to leap into the air. When they are hooked they make one deep dive with tremendous strength, and it not rarely happens that they break the branch line or drag a glass ball float of 30 centimeters diameter so deep that it is crushed by water pressure.

2. Albacore, Germo germo (Lacépède)

This fish is called both binnaga and binchō and in western Japan it is generally called tonbo or tonboshibi. It is small for a tuna, specimens of about 100 centimeters long and 30 kilograms in weight being considered large.

A peculiar characteristic of this species is the long pectoral fins, the tips of which reach back beyond the base of the second dorsal. The back is blue-black in color and the belly is silvery-white.

The color of the flesh is pale pink, almost white, and the flesh is extremely soft, making it rather unsuitable for consumption as sliced raw fish. When it is cooked, it does not become hard as the other tunas do, and as the flavor is said to resemble chicken, it is highly prized by Americans, who call it the "chicken of the sea." Before the war this species was exported in large quantities canned in oil. The center of this canning industry was in Shizuoka Prefecture. Besides this canned fish, rather large quantities of fresh fish were exported as raw material for canning. Even today after the war, the demand from America appears to be rather great.

This is a very widely distributed species, ranging from the Equator to about 45° N. and S. latitudes. The center of their distribution in the North Pacific, however, appears to be between 30° and 40° N. latitude. They are abundant in Japanese waters and are taken in large numbers by skipjack boats fishing with live bait in the summer. From December to March, they are taken over an extremely broad area centered around 30° N. latitude, principally by longlines.

Some scholars think that the albacore of Japanese waters, of the Southern Hemisphere, of the Indian Ocean, and of the Atlantic Ocean are all the same species. In view of their distribution, this opinion may be thought reasonable, but the ultimate decision remains to be made in the future.

3. Bigeye tuna, Parathunnus sibi (Temminck and Schlegel) = Parathunnus mebachi (Kishinouye)

This fish is also called bachi, darumashibi, and mebachi. Among the tunas it is the next largest to the black tuna, attaining a length of about 2 meters and a weight of about 150 kilograms.

Characteristics peculiar to this tuna are the stout body, the short tail portion (from the vent back), and the large head and eyes. The name darumashibi applies chiefly to immature fish, the thick, chunky body probably being reminiscent of a statue of Daruma. The pectoral fins are long, their tips reaching to a point roughly below the insertion of the second dorsal. The back is bluish black and the belly is white.

The flesh has a rather pale but beautiful red color. When it is served as sliced raw fish, the flavor is not considered particularly good, but it is at its best in the spring and autumn. The fact that the flesh is somewhat soft is considered a defect. Besides being eaten fresh, it is utilized along with yellowfin for canning.

The species has not yet been reported from the Sea of Japan, but it has a very wide distribution. It is an interesting fact that this species has no clearly apparent focus to its distribution, being taken in about equal abundance everywhere from 0° to 40° N. The trends of the catch rates are not correlated with latitude, but they appear to improve toward the center of the Pacific. In the overall picture the bigeye is taken at a rate of about 0.5 fish per hundred hooks. The species appears to be most abundant in Japanese waters from September to December. It generally prefers to live at deep levels, however, it is not yet known with certainty exactly what depth it prefers. As it has the habit of coming into the surface levels at night, it is sometimes taken in drift nets and it is said that this occurs particularly often on moonlight nights. These fish tend to be somewhat more abundant in tropical seas, and in both the Pacific Ocean and Indian Ocean areas they are taken in the proportion of about 10 percent of the yellowfin catch.

4. Yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel)

This fish is also called gesunaga, hirenaga, kibire, and itoshibi. In the southern Kyūshū area when the word shibi is used, this species is meant. Jordan distinguished the yellowfin and the itoshibi, giving to the latter the scientific name Neothunnus itosibi, but this is thought to have been clearly a mistaken interpretation of the characteristic morphological changes which accompany growth in this fish.

Yellowfin are generally somewhat smaller than bigeye tuna, attaining a length of about 2 meters and a weight of around 70 kilograms.

A characteristic of this fish is the length of the caudal portion, that is the part of the fish behind the vent. In mature fish the second dorsal and anal fins are remarkably elongated. The names hirenaga and itosibi are expressive of this peculiarity. These fins and the finlets which follow them are of a bright yellow color. The names kihada and kibire are based on this characteristic. The pectoral fins are rather long, reaching to a point slightly back of the insertion of the second dorsal.

The color of the flesh is a rather pale red which looks extraordinarily bright to the eye. In western Japan this fish is generally more highly regarded than the black tuna. When eaten raw the flavor is rather faint, but it is particularly delicious during the summer. Besides being consumed fresh, it is exported canned in oil and the scrap meat produced by the canning operation is made into stew. The young fish are frequently taken in fixed gear or by pole and line and are manufactured into the so-called shibibushi by the same methods used in making dried skipjack sticks.

The range of distribution extends from the Equator to about 35° N. latitude, but the areas in which this species is the object of a fishery are a comparatively narrow belt along the Equator, and the series of enclosed waters comprising the South China, Sulu, and Celebes seas. The yellowfin become more abundant in the North Pacific during the summer, and are most numerous in the waters of the Ogasawara Islands from June to July and in November. At that time they are caught at a rate of about 1.5 fish per hundred hooks. They are taken, though extremely rarely, in the Sea of Japan.

5. Koshinaga, Kishinoella rara (Kishinouye)

Northern bluefin (Australia).

This fish is also called bintsuke. In Formosa it was called the seiban maguro. This is the smallest of the tunas, fish of about 70 centimeters long and weighing about 7 kilograms being already mature. Dr. Kishinouye placed this fish in the same genus with the yellowfin tuna, but it is given here as Kishinoella in accordance with the opinion of Jordan and Evermann, who said that because of morphological differences it should be placed in a separate genus. According to recently received reports, K. rara is a synonym of the northern bluefin, K. tonggol, which has long been known in the coastal waters of Australia.

In outer appearance this fish closely resembles young yellowfin and is difficult to distinguish from them, but the color of the flesh is a great deal paler than in the yellowfin, being nearly white. The back is bluish-black, the belly is greyish white, and like the young stages of other tunas, it has oblique rows of long and narrow colorless dots, which may appear grey depending upon the angle at which they are seen. The second dorsal and the anal are not prolonged into filaments. The finlets are yellow as in the yellowfin but are edged with black. The pectoral fins are rather long, reaching to a point somewhat behind the insertion of the second dorsal fin.

The flesh is pale red, almost white, and when served as sliced raw fish, it has a very beautiful appearance and a very fine flavor. It is particularly delicious during the summer. This species is rare in Japan, being taken by trolling during the winter off the south coast of Kyūshū. It is a great deal more coastal in character than the other tunas, and is common in the vicinity of small islands in the tropics and sub-tropics. In Formosa it is taken throughout the year by trolling, and is particularly abundant from February to March and around August.

The above five species are all of the tunas that occur in Japanese waters. The koshinaga is entirely without significance as an element in the tuna longline catch.

B. Spearfishes

As with the tunas, a great number of species of spearfishes have been reported from various parts of the world, the number being actually in excess of 30 species. It is, however, very doubtful whether so many species really exist. The reason that such a large number of species have been reported is probably that these fish are difficult to study and there has been no thorough comparative study made.

The writer has some new opinions considering the classification of the spearfishes, but as these will be published elsewhere, the notes given here are based on the hitherto accepted classification.

1. Shortnosed spearfish, Tetrapturus angustirostris (Tanaka)

? angustirostris = belone = brevirostris

This fish is also called sanmakajiki. It is the smallest of the spearfishes and rarely surpasses a length of about 2 meters and a weight of about 20 kilograms. It is easily distinguished from other species by such remarkable characteristics as the shortness of its lanceolate upper jaw, the height of the central portion of its dorsal fin, and the absence of markings on the sides of its slender body.

The flesh is of the so-called "spearfish color" but rather pale, and although it has a beautiful appearance when served as sliced raw fish, it is lacking in fat and is not very well flavored.

This is a remarkably pelagic species, and it appears not to occur in coastal nor in enclosed seas. In Japanese waters it occurs in the open sea south of 35° N. latitude, but its density of distribution is not very high. It occurs rather densely in the waters east of Formosa and the Philippines from November to January, at which season it spawns. Up to the present it has not been of great importance to the fishery. The name angustirostris was given to this species by Dr. Shigeo Tanaka, however, this is probably the same species as that reported from the Atlantic Ocean under the name of belone and from the Indian Ocean as brevirostris.

2. Sailfish, Istiophorus orientalis (Temminck and Schlegel)

Umbrella spearfish (Formosa).

This species is also called nairagi, nōrage, baren, and sugiyama. It attains a length of about 3 meters and a weight of about 60 kilograms. The spearshaped upper jaw is comparatively long and the development of the ventral fins is also remarkable. The body is notably compressed laterally and elongated and there are between 10 and 20 transverse bands formed of cobalt colored spots on the sides of the body. The most remarkable characteristic is the very great development of the first dorsal fin. Most of the names for this fish are based on this character.

The flesh is rather dark pink, inferior in appearance to other species, and the flavor also appears inferior. It is, however, very well flavored at some seasons, particularly from April to June.

The sailfish occurs throughout the year comparatively close to islands in warm seas, and it appears in Japanese waters in the summer. It spawns in Formosan waters from April to August. The juvenile fish differ greatly in appearance from the adults, and have conspicuous spines on their heads.

The spearfishes, when they are hooked, generally make a series of leaps into the air, after which they struggle at the surface attempting to flee in a horizontal direction so that they tangle the lines and are very troublesome. They also have the habit of swimming at the surface with the upper lobe of the caudal fin and sometimes a part of the dorsal fin exposed. This habit is utilized by the harpoon fishery which is carried on at a number of widely separated places.

3. Striped marlin, Makaira mitsukurii (Jordan and Snyder)

Spearfish or Blue-marlin (?) (America).

Red-fleshed spearfish (Formosa).

This species is sometimes called akakajiki (red marlin) to contrast it with the white marlin and black marlin. It is not very large for a spearfish, but it does attain a length of about 2.5 meters and a weight of around 120 kilograms.

The body is elongated and strongly compressed laterally with between 10 and 20 transverse bars on its sides formed by assemblages of cobalt spots. The third to fifth spines of the first dorsal fin are the highest, the height exceeding the body depth. The upper jaw is longer in proportion to the lower jaw than in other species of spearfish.

The flesh is a beautiful pale red color, the so-called "spearfish color," and both its appearance and its flavor are considered very good when it is served raw. The price is consequently high.

These fish are always present in warm seas. They are quite pelagic in nature and appear to be taken in rather large numbers in the vicinity of small islands in the open ocean. In the Ogasawara Islands area they are most abundant from May to July, and they appear to range north to the vicinity of 40° N. latitude. In Formosan waters the catch of this species begins gradually to increase in January and is at its peak in May at which time the fish spawn. They appear to move north along the continental side of the Kuroshio and are rather abundant on the East China Sea side of the Okinawa archipelago. They also appear in the Tsushima Strait area and some of them seem to enter the southern part of the Sea of Japan.

4. White marlin, Makaira marlina (Jordan and Hubbs)

Black marlin (America).

Standing-wing spearfish (Formosa).

This fish is also known as the shirokawa kajiki, shiro, and katahari. This is the largest of all the tunas and spearfishes, the biggest specimen the writer ever encountered in his studies having been slightly less than 4 meters in length and 564 kilograms in weight. According to the fishermen, there are records of even larger specimens having been taken.

The body depth is great, and that portion of the body forward of the vent is strongly compressed laterally. The part of the body anterior to the insertion of the first dorsal fin rises up sharply, giving rise to the name katahari ("square shoulders"). No bands of cobalt spots can be seen on the sides of the body. The structure of the pectoral fins is completely different from that of the other species, and as these fins stand out at approximately right angles from the sides of the body, this fish is called the "standing-wing spearfish" in the Formosan language. In all of the other species the pectoral fins can be folded in along the sides of the body, but the white marlin is conspicuously characterized by the fact that this cannot be done without destroying the articulation of these fins.

The color of the flesh appears to be somewhat lighter than that of the striped marlin. It is difficult to generalize on this point because in this species, as in others, the color of the flesh appears to vary somewhat with the area and the season. Both the appearance and the flavor are very good when the fish is served sliced raw. It is especially flavorful when there is abundant fat.

These fish occur throughout the year in warm seas. It appears that their distribution extends to rather high latitudes and the northern limit of their distribution in Japanese waters is not clearly known. In the southern sea areas they appear to be particularly abundant in such enclosed waters as the Celebes Sea, Sulu Sea, and South China Sea, and it seems that they are generally numerous in the vicinity of islands. In Formosan waters they are taken in the greatest numbers on the South China Sea side from October to December, and they are most abundant in the Kuroshio in February and March. In the East China Sea in general, they are taken along the 100-fathom line, and they reach the Saishūtō (Quelpart Island) area.

It is an interesting fact that there is a marked difference in size between the sexes, the males being generally small and the females large. The males reach a maximum weight of 130 kilograms, but the biggest female recorded was 564 kilograms. The same phenomenon is seen in the case of the black marlin, as will be noted later, but in this case the males attain weights of only about 100 to 120 kilograms and all fish over this size are females. As yet no adequate biological explanation can be given for this phenomenon.

5. Black marlin, Makaira mazara (Jordan and Snyder)

Crow-skin spearfish (Formosa).

This fish is also called kūro, kurokawa, and genba. It is not clear what this species is called in the United States. The name mazara is derived from the name mazaara used in the Bōshū region, but it is very doubtful whether the fish reported as a new species by Jordan and Snyder was a black marlin, the present author inclining to the opinion that it was not. However, the presently accepted name mazara will be employed here.

The body is very stout with the lateral compression less marked than in other species. The fish looks shorter than other species. There are from 10 to 20 transverse bars on the sides of the body made up of cobalt spots. Scales are more deciduous than in other species, and where they come off the body is a brownish color. The snout tapers sharply, and the length of the upper jaw is slightly more than twice that of the lower jaw. The lateral line is extraordinarily obscure, but when carefully examined it can be seen to be not simple but complexly branched, a characteristic of this species.

The color of the flesh is not greatly different from that of the striped marlin or the white marlin, but this species generally contains more fat, and those taken in Formosa from March to May are sometimes called "oily spearfish." The flavor is considered inferior to that of the striped marlin, but this depends upon the season and the area, and those taken around April and May make extremely delicious sashimi.

These fish are particularly abundant in the open seas of warm latitudes, and they appear everywhere in the North Equatorial Current. In the coastal waters of the Ogasawara Islands they appear after the striped marlin. They range farther to the north, but the northern limit of their distribution is not known. In the southern portion of the Kuroshio, that is off Formosa and the Philippines, they gradually increase in abundance beginning around March and reach their peak around August and September. This does not differ greatly from the situation in the Ogasawara area. In August and September they are rather abundant in waters west of Kyūshū and the vicinity of Saishūtō (Quelpart Island). They spawn east of Luzon from May to July

6. Broadbill swordfish, Xiphias gladius (Linnaeus)

Swordfish (England-America).

This fish belongs to a different family from the spearfishes listed above. It is also called meka and tsun, the former name being used in the area around Tokyo and the latter being employed in Kyūshū.

The upper jaw is very long, being more than 7/10 of the length of the body. In most of the spearfishes, the upper jaw is slender and cylindrical, but in this species it has the form of a two-edged sword. A remarkable characteristic of this fish is the complete absence of ventral fins, of which there is not even a trace. It also differs notably in outer appearance from the other spearfishes in that there are no scales, both jaws are without teeth, and the keels on the caudal peduncles, of which there are two pairs in the istiophorids, are single in this species. The back is bluish-black with a leaden cast, and the belly is white, but the fish appears to have an all-over yellowish-brown cast. The flesh is nearly white, soft, very oily, and not particularly prized as sashimi. It is however, palatable when cooked and seasoned and is greatly liked by Americans.

This fish has a wide range of distribution and is known from warm seas throughout the world. In Japanese waters, it is abundant off northeastern Japan and although a fish of temperate seas, it is numerous in rather high latitudes. It is taken by harpooning and by the longline fishery.

In addition to these tunas and spearfishes, the tuna longline fishery takes cybiids, dolphin, skipjack, moonfish, and sharks. Aside from the sharks, these other fishes can hardly be said to be important in terms of numbers. The sharks not only are taken in large numbers and have an important significance as part of the catch, but they also demand attention as pests which damage the fish caught on the longlines. Leaving aside this purely commercial significance, they are worthy of considerable attention from the biological standpoint.

C. Sharks

There are a great many species of sharks, but among them the following 10 or so species have an especially close connection with the tuna longline fishery.

Differences can be detected in the habits of these various species. Some of them have a distribution and a migrational habit resembling that of the yellowfin, while others move in a way resembling some of the spearfishes. In some cases their migrations precede and in others they follow those of the tunas and spearfishes. As almost nothing is known as yet of these relationships, it is far from the stage of practical application, but if thorough studies are made, it may be thought that there is ample possibility of using these sharks as indicators of fishing grounds and fishing seasons. Hitherto, there have been no studies at all from this point of view, however, but in the future this sort of work should be emphasized.

1. Aozame, Isurus glaucus (Müller and Henle)

Also called aoyagi, iragi, and shibibuka.

The body is spindle-shaped, and the snout is pointed and equipped with sharp teeth. It reaches a length of about 4 meters. The back is a deep indigo blue and the belly is white. This fish occurs widely in warm seas south of central Japan, but is not abundant. The skin is said to be the best for leather of any shark skin.

2. Rakudazame, Isurus nasus (Bonnaterre)

Also called mōka and nezumizame. This fish is stouter than the aozame. Whereas the aozame is a warm-water species, this species prefers cold waters and is numerous from northeastern Japan northward. In northeastern Honshū a longline fishery has developed which has this shark as its special object. This is the so-called mōkanawa.

3. Hachiware, Alopias profundus (Nakamura)

Foxshark or thresher shark (England).

This is one of the thresher shark family and its caudal fin is broad and equal in length to the rest of the body. The eyes are large and of the shape of a gourd turned upside down. This shark attains a length of more than 4 meters and inhabits warm seas.

4. Onagazame, Alopias pelagicus (Nakamura)

Foxshark (England).

This shark resembles the preceding species, but its caudal fin is longer than the rest of the body and narrow. The eyes are small and of a green-gray color whereas in the preceding species the eyes are of a blackish-gray color. This species is widely and generally distributed in warm seas. Both species attain a length of about 4 meters. It appears that there is yet another very similar species but little is known of it at present.

5. Itachizame, Galeocerdo arcticus (Faber)

There are brown markings on the body. Large specimens attain a length of 3 meters. This is a very widely distributed shark, ranging from the Equator to the vicinity of 80° N. and S. latitude. It is generally most abundant in the vicinity of islands and often eats gulls and other water birds, for which reason it is called the "bird shark" in Formosan Chinese. It is an extraordinarily voracious animal, and human bones and so forth are found from time to time in its stomach.

6. Dotabuka, Carcharinus brachyurus (Günther)

This shark will grow to a length of about 2 - 2.5 meters. The first dorsal fin is notably small and is located mid-way between the snout and the caudal peduncle. The second dorsal fin is smaller than the second anal fin and is located diametrically opposite it. The snout is blunt. This is one of the species of sharks commonly seen in warm seas.

7. Yashibuka, Carcharinus sp. (gangeticus ?)

This shark resembles the preceding one but can easily be distinguished by its remarkably large first dorsal fin. This fin is the best for making dried shark fins used in Chinese cooking and is of high value. This species is abundant in warm seas. They are particularly numerous in the waters east of Formosa in February and March.

8. Mejirozame, Carcharinus japonicus (Temminck and Schlegel)

Characteristics peculiar to this species are the small eyes and gill openings. They are said to be very abundant in Japanese waters, but it is doubtful whether all the sharks to which the name mejirozame is applied are of the same species. It is thought that there is need for further study on this point.

9. Tsumaguro, Carcharinus melanopterus (Quoy and Gaimard)

Particularly outstanding characteristics of this shark are the intensely black tips and edges of all the fins. It attains a length of 2 - 2.5 meters. As it is abundant in southern seas, it is taken in rather large quantities. These sharks appear to be particularly numerous in the South China Sea area.

10. Tsumajiro, Carcharinus albimarginatus (Rüppell)

This species is distinguished by the white tips and edges on all of its fins. It does not grow very large, the maximum size being about 2 meters long and 30 kilograms in weight. This species is very commonly seen in warm seas. There is another separate species called the yogorebuka or baka, but it is not yet well known biologically. In this species the tip of each fin has cloud-like irregular white spots.

11. Shūmokuzame, Sphyrna zygaena (Linnaeus)

The head is in the form of a wooden mallet with the eyes on the tips. In western Japan it is generally called kasebuka or kase. One species occurs in Japanese waters, but three species have been reported from the south. It is wondered whether those occurring in Japanese waters should not also be separated into three distinct species.

V. Fishing Grounds

As has been stated earlier, the fishing grounds of the tuna longline fishery are located within the area from the Equator to about 40 to 45° N. latitude in the open sea and in coastal waters facing on warm currents. We do not as yet have adequate data concerning the situation in the Southern Hemisphere and therefore know little about it, but it may naturally be supposed not to be greatly different from that of the Northern Hemisphere. The occurrence of many species of tuna and spearfish has been reported from Australia and the New Guinea area. It appears that recently tuna fisheries are being developed in that region.

Until recent years tuna fishing grounds were limited to coastal waters and to the vicinity of islands and shoals (eminences in the sea floor) scattered throughout the open sea. This was partly because the fishes sought after are abundant in waters having this topography, but it was also due to the impossibility of operating in the open sea without landmarks when the capabilities of the fishing vessels and the navigational arts of the fishermen were so inadequate.

The abundance of fish in the vicinity of oceanic islands and shoals is explained principally from the point of view of the food supply as the sea waters are stirred up in the vicinity of such places enriching the surface layers with nutrient salts from the rich, deep layers and promoting the growth of plankton while gyrals concentrate the small animals which serve as food for the tunas. There is still room for doubt as to whether or not this sort of explanation exhausts the subject, but at any rate the tunas are observed to remain during certain periods of time in the vicinity of such topographical features. This phenomenon is called "setsuki" and such fishing grounds are called setsuki or shoal fishing grounds. On such fishing grounds fish are always comparatively abundant, offering superior conditions for fishing.

Formerly there was a time when it was believed that such topography was probably essential to the development of tuna fishing grounds and at that time explorations for new fishing grounds meant a search for islands and shoals. In recent years with the progress of the shipbuilding art and the improvement of navigational techniques, fishing grounds have been very rapidly extended and the foregoing concept has been completely abandoned as it has come to be realized that any place in the ocean can become a fishing ground if one succeeds in intercepting the route of migration of the schools. The mid-Pacific albacore grounds are a good example.

Under the heading "General Outline of Fishing Grounds and Fishing Seasons" a brief account was given of the fishing grounds in Japanese waters. In the present section the Indian Ocean and the Pacific Ocean will be divided into a number of areas each of which will be described in terms of its characteristics and significance as a fishing ground.

The data used here are all the results of the work of research vessels. The data gathered by ordinary commercial fishing vessels have many shortcomings and there are grave doubts concerning their reliability. For this reason, I have decided to use none of them. I understand to some extent the feeling of the commercial fishermen in not wanting to inform others of their good fishing grounds, but it goes without saying that this attitude is extremely disadvantageous as an obstacle to the mutual interchange of knowledge and experience. The interchange of accurate data is desirable both for the present mutual profit of persons engaged in the fishery and for the healthy development of the industry.

Some of the data gathered by research vessels have been lost. In others there are imperfections and doubtful points, which in most cases have not been corrected despite the passage of time since they were gathered, and from these points of view I have found not a few occasions for dissatisfaction. Furthermore, because the distribution of the data by area and by season has been extremely uneven, it has been almost impossible to find out the changes in the fishing seasons and the movements of the schools throughout the year for all the fishing grounds. It is believed that the reason for this is to be found in the defects in the system which has operated hitherto. That is, each research vessel has, in addition to the duty of providing guidance for the fishing vessels from its locality, had to bear the burden of a very heavy income budget. For this reason, they have carried out their obligations to the income budget rather than try to attain the basic purposes of a research vessel, and have all striven to fish on the same grounds at the season when they could anticipate sure catches.

It is highly regrettable that this situation has not only not been completely corrected at present, but in fact has rather been aggravated. This fact should give an important suggestion concerning the proper management of fisheries research activities. The objectives of the study of oceanic resources cannot be attained by having each research vessel operate in accordance with its own particular opinions and with the main objective of catching fish. However, the execution of a research program based on a coordinated plan for the disposition of the vessels and ignoring the question of income would require a great deal of money and would be completely impossible to a weak economy.

What has been said here does not mean of course that the work of research vessels in the past was completely without significance. As will be set forth in the following, it is possible in some degree to learn the characteristics of the various fishing grounds. It has, however, been possible to learn only very little concerning the movements of the schools and the accompanying changes in fishing grounds and fishing seasons, questions which it was hoped at first would be clarified by this study.

A. Indian Ocean Region

The waters to the south and west of the Greater and Lesser Sunda archipelagos will be described as the Indian Ocean Region. Almost all of the data for this area were gathered by the training ship Hakuyō Maru of the Fisheries Institute of the Ministry of Agriculture and Forestry and the research vessel Haruna Maru of the Fisheries Bureau of the Ministry of Agriculture and Commerce. In addition the fisheries research vessel Shōnan Maru, of the former Formosa Government-General and the mothership-type tuna fleet of the Tōbu Fisheries Company operated experimentally in this region. There is also a small amount of data for the area from the research vessel Zuihō Maru of the South Seas Government-General.

It appears that before the war some Japanese fishermen were trolling out of Singapore, but there was no real tuna fishery operated either by Japanese or by the natives of the region. During the war many fishing boats operated in this area in order to supply food for the troops. They appear to have been fairly successful, but they left no records at all.

Nothing is known of the situation since the war. As the natives have no knowledge or experience of this type of fishery, it cannot be thought that there is any possibility at present of their operating a longline fishery. Consequently, it is believed that these waters remain almost completely virgin grounds for the tuna fishery. However, as has already been said, it appears that a start has already been made in Australia, and Ceylon and Pakistan also seem to be showing an extraordinary interest in fisheries, so the waters of this region will probably be developed as fishing grounds in the not far distant future.

This region has been subdivided as follows:

1. Waters around the Andaman and Nicobar islands.
2. The west coast of Sumatra.
3. Waters around Java.
4. Waters around the Lesser Sunda archipelago and Timor.

In addition to these four areas, the Hakuyō Maru made a survey in the vicinity of 4° N. latitude, 75° E. longitude, but as the data were few they have been omitted from consideration.

1. Waters around the Andaman and Nicobar islands (6° to 15° N., 90° to 97° E.).

As we have very few data concerning oceanographic conditions in this sea area, their details are unknown. In this region the year is divided into two seasons, in one of which the northeast winds blow continuously, while in the other southwesterly winds prevail. The former corresponds to the winter of the Northern Hemisphere and the latter to the summer. These seasonal changes are accompanied by marked differences in oceanographic conditions.

The currents during the period from July to September when the southwesterly winds are at their strongest are roughly as follows. There is a current which flows in the vicinity of 5° N. and this current divides into two branches to the west of the northern tip of Sumatra. One branch flows to the southeast along the west coast of Sumatra; the other flows north-northeast along both sides of the Nicobar and Andaman archipelagos. The speed of these currents is about 0.5 to 1 knot.

From January to March, when the northeasterly winds prevail, the ocean currents are almost completely opposite to their pattern during the period of southwesterly winds. They flow in a clockwise direction in the Bay of Bengal, flow south along the islands, and turn to the westward in the vicinity of the northern tip of Sumatra.

As we have no data for the season of southwesterly winds, it is impossible to explain the situation as regards water temperatures and salinity. Combining the data for the period from December - January, it is indicated that the surface water temperature is slightly less than 28° C., the temperature at the 50-meter level about 27.5° C., at 100 meters 23° to 24° C., and at 200 meters about 14° C. Transparency shows rather low values, within the range of 9 to 18 meters. The water color is generally III on Forel's scale.

During the season of northeasterlies, strong winds blow from time to time and it is thought that it would sometimes be difficult for small vessels to operate. However, in general, fine weather prevails and it is believed that weather would prove no obstacle to the operation of large vessels. As the season of southwesterly winds corresponds to the rainy season in this region, there are many squalls and typhoons attack the region from time to time, so there would probably be not a few cases in which the weather would interfere with fishing operaticns.

In the investigations of the Hakuyō Maru frozen squid were used as bait, frozen herring and squid having been used by the Haruna Maru. The Hakuyō Maru also investigated local bait supplies and concluded that while it would not be impossible, it would be extremely difficult for a fishing boat to obtain its own supplies of bait in the area.

The surveys of the Hakuyō Maru and the Haruna Maru were made between 1930 and 1933. The investigations were carried on only during December and January, so that there are no data at all for any other seasons of the year. Consequently the oceanographic conditions at other times are completely unknown. Table 10 shows the fishing conditions revealed by these explorations. The figure in the table is the number of fish captured per hundred hooks fished. This will be referred to hereafter as the catch rate.

Table 10.--Fishing conditions in the Andaman and Nicobar islands

Number of hooks fished	Yellowfin		Bigeye		Spearfishes		Total	
	Fish	Catch rate	Fish	Catch rate	Fish	Catch rate	Fish	Catch rate
17,348	1,179	6.80	43	0.25	70	0.40	1,292	7.44

The combined catch rate for tunas and spearfishes is 7.44, indicating a rather superior fishing ground.

As for the composition of the catch, yellowfin tuna were most important, being more than 91 percent of the total tuna and spearfish catch. Bigeyed tuna were slightly more than 3 percent and spearfishes slightly less than 5 percent. If these values are compared with those for other sea areas, they indicate that at the season when the survey was made, the catch of bigeyed tuna and spearfishes in this area is remarkably low. As we have no data, we know absolutely nothing of the fishing conditions and the composition of the catch at other seasons.

Looking at the variations in the fishing situation by areas, it is clearly indicated that the catch rates tend to be high in the south and low in the north. On the other hand, a trend is indicated for the size of the yellowfin to be greater in the north and smaller in the south. In other words, in the south the catch rate is high but the fish are small, while in the north the catch rate is low and the fish are large.

Looking at the changes in the fishing conditions by seasons, within the period December-January there is clearly a tendency for the catch rates to rise gradually with the passage of time. From January 27 to 31, 1932, the catch rates of the Hakuyō Maru showed an astonishingly high average of 19.65, and on the 27th and 28th of January 1930, the catch rates were also high, being 16.67 and 12.33 respectively.

This trend of increase and decrease in the catch rates with the season is similar to that which can be seen in the waters off the west coast of Sumatra which adjoin this sea area to the south, and therefore can be thought to indicate the migrational pattern of the schools in the northeastern part of the Indian Ocean. As will be detailed later, in the northern part of the Sumatran waters the catch rates gradually increase from November on, showing a tendency to a continuing increase until at least February.

The foregoing is a general outline of fishing conditions for tunas and spearfishes. The Hakuyō Maru's reports contain absolutely no records concerning sharks, which follow these fishes in importance. According to the reports of the Haruna Maru, the catch rate for sharks was 1.84. This means that at that season sharks were taken at the rate of about 2 for every 100 hooks fished. Damage to the catch by sharks appears to have been rather great, but we have no detailed information on it. Miscellaneous fish mixed in with the catch were skipjack, dolphin, and cybiids, but they were few in number and of little significance.

The gear used by the Hakuyō Maru had branch lines of two different lengths, the construction being as follows:

Type of branch line	Number of branch lines	Length in feet
Long branches	2	99
Short branches	4	30

The length of the float lines was 90 feet. The following table shows the catch made by the long and short branch lines of this gear.

Table 11.--Fishing results by type of branch line (Hakuyō Maru, waters of Andaman and Nicobar islands)

Date	Long branch lines		Short branch lines	
	Number of fish	Percentage	Number of fish	Percentage
Jan. 1931	81	71	32	29
Dec. 1931	76	73	28	27

The percentage figures in this table are the proportion of the total catch taken by each type of branch line.

As the foregoing table shows, the long branches gave much better results than the short branch lines. Indeed, if we compare the number of hooks actually used on each type of branch line, there were twice as many short branches as long branches used, and therefore the catch rate of the long branch lines was from 5 to 6 times greater than that of the short branch lines. These facts indicate that short branch lines are much less suitable than long ones as fishing gear for this sea area. If we assume that the sum of the float line and branch line lengths gives the depths at which the hooks are hanging, the depth was 120 feet in the case of the short branches and 189 feet in case of the long branches. As there is in actuality considerable sag in the main line, the positions of the hooks were deeper than this. The problem of what depth gives the best catch rates cannot be settled simply by this sort of comparison of two kinds of branch lines, however, in view of the length of these long branch lines it is believed that the yellowfin swim at rather deep levels in this sea area.

Because of the lack of data we have no way of knowing anything about seasonal changes in fishing conditions, but it is at any rate certain that this is a rather superior fishing ground from December to January. Judging by analogy with the fishing conditions in the waters off Sumatra, it is probable that the good fishing continues through February and that the fishing improves with the passage of time during this period.

2. West coast of Sumatra (6° N. to 8° S., 90° to 105° E.)

Most of the data for this sea area are from the operations of the Haruna Maru and the Hakuyō Maru. In addition a small amount of data has been reported by the Shōnan Maru. These investigations were confined to waters very close to shore and the situation farther offshore is not known.

The pattern of the currents is roughly as follows. During the period from July through September, when southerly winds blow continuously, there is a rather strong current flowing eastward at 5° N. from the central portion of the Indian Ocean. The current divides into two branches near the northern end of this sea area, one branch running north along the Nicobar and Andaman islands, and the other flowing southeast along the coast of Sumatra. In the vicinity of 5° S., that is near the Sunda Strait, there is a very clear current boundary. This boundary extends southwest from the vicinity of Sunda Strait, and from around 100° E. longitude it runs west approximately along the line of 8° S. latitude. South of the boundary a strong current flows west from the waters off the south coast of Java while to the north of the boundary the current flows southeast as mentioned before.

From January through March, the season when northerly winds prevail, the pattern of the currents changes completely. At this season a current boundary appears running east and west along the Equator; north of this boundary, the currents flow northeast and south of it there is a current flowing southeast along the shores of Sumatra. The current north of the Equator turns westward in the vicinity of the northern extremity of this sea area around 5° N. latitude and joins the current flowing south along the Nicobar Islands. Another conspicuous current boundary appears around the southern limits of this sea area. This boundary runs approximately east and west in the vicinity of 8° to 10° S. latitude, and on its south side the cold current flowing up the west coast of Australia turns to the westward. Because of this current, the current flowing southeast along the west coast of Sumatra is pressed against the coast of Java, forming a narrow but strong flow to the eastward. During the season of northeasterly winds, as remarked earlier, this sea area is cut off from adjacent waters by conspicuous current boundaries at its north in the vicinity of 5° N. latitude and to the south in the vicinity of 8° S. latitude. There is another current boundary at about the center of the area near the Equator. The line of this boundary runs east and west along the Equator, turning to the southwest in the vicinity of 98° E. longitude. Accordingly, this sea area is divided into a number of parts having currents of different character.

These various currents appear to be rather strong, and according to the reports of the Haruna Maru, speeds of 2 to 3 knots were frequently measured.

As we have no data for the season of southerly winds, we know nothing of oceanographic conditions at that time of the year. During the season when northerly winds prevail, the water temperatures are in general higher than those of the Nicobar Islands region, with slightly over 28° C. at the surface, slightly less than 28° C. at the 50-meter level, and around 24° to 25° C. at the 100-meter level on the average. Higher values are shown for transparency than in the Nicobar and Andaman islands waters, the values running about 30 meters. The water color is in most cases I or II on the Forel scale.

The season of southerly winds corresponds with the rainy season in this region and there are many squalls. Wind and waves are generally high and typhoons occur from time to time. It is thought that the weather will interfere frequently with fishing operations. This sea area, except for its northern extremity, is generally calm during the season of northerly winds and fishing operations are usually very easily carried on.

The investigations of the Haruna Maru and the Hakuyō Maru cover the period from November through February. The data from the Shōnan Maru were collected in August in the vicinity of the Sunda Strait. It is said that the mothership-type operation of the Tōbu Fisheries Company also entered this area, but as there are no data from this venture we do not know what conditions they found there. If we summarize these various data in a table, the fishing conditions in this sea area may be shown as follows.

Table 12.--Fishing conditions off the west coast of Sumatra

Number of hooks used	Yellowfin		Bigeye		Spearfishes		Total tunas and spearfishes		Total sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
151,508	12,904	8.52	1,350	0.89	1,078	0.71	15,332	10.12	1,530	1.01

As the table shows, the combined catch rate for tunas and spearfishes is over 10, indicating that this sea area is an extremely good fishing ground.

Compared with the waters of the Andaman and Nicobar islands described above, the catch rates in this sea area are conspicuously higher. Yellowfin, bigeye tuna, and spearfishes are all shown to be more abundant in this area. The shark catch rate on the other hand is lower. The table shows that the main factor in the greater catch rate in this area is the increased catch of yellowfin tuna, but note must also be taken of the remarkable increase in the bigeye catch.

The data are limited to the period from November through February, but they afford a basis for considering that the seasonal changes in fishing conditions are fairly great. The following table shows the catch rates for each species grouped by months.

Table 13 brings together data from investigations covering several years. It may naturally be thought that there is a certain amount of variation from year to year, however, for the period from November through February, a general tendency for the catch rates to gradually rise with the passage of time can be clearly detected. Data for the season of southerly winds are, as the table shows, very few and are inadequate as a basis for forming any sort of an opinion, but it is thought that some catch can be anticipated at this season.

Table 13.--Fishing conditions by months (off the west coast of Sumatra)

Month	Number of hooks used	Yellowfin		Bigeye		Spearfishes		Sharks	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Aug.	300	9	3.00	0	0.00	2	0.66	4	1.33
Nov.	7,800	341	4.37	65	0.83	31	0.40	40	0.51
Dec.	51,488	4,540	8.80	575	1.12	249	0.48	457	0.89
Jan.	75,568	6,782	8.98	615	0.81	612	0.81	866	1.15
Feb.	16,352	1,732	10.59	95	0.58	184	1.13	163	1.00

In the composition of the catch, the yellowfin are overwhelmingly predominant, amounting to 84 percent of the total for all tunas and spearfishes. Bigeye tuna are slightly less than 9 percent and spearfishes slightly more than 7 percent of the catch, these proportions representing a conspicuous increase over the catch of the species in the Nicobar region.

The seasonal changes in the catch rates for the various species are as shown in the foregoing table. The bigeye catch rate reaches its peak in December and thereafter gradually declines. Both the spearfishes and the yellowfin tuna show a tendency to a gradual increase with the passage of time, at least up to the end of February. The sharks in general exhibit the same trends of increase and decrease as the yellowfin and spearfishes, but in addition to the seasonal changes they also appear to vary remarkably from one area to another, the catch rates appearing to be larger close to shore.

Damage to the catch by sharks appears on the whole to be proportional to the catch rate of sharks, and on the days when large numbers of sharks were taken the damage from sharks was also great. According to the reports of the Haruna Maru, the maximum shark damage was actually 40 percent. This high rate was however rather exceptional and in general the damage rate was about 10 percent.

Considering the situation in the various parts of the area, it appears that whereas the fishing conditions north of the Equator were comparatively stable, to the south of the Equator and particularly in the waters off the Sunda Strait, which are at the southern limit of this area, the fluctuations in the fishing conditions appear to have been extremely pronounced.

The average weight of the fish in each day's yellowfin catch was reported. The data indicate that the majority of the fish taken north of the Equator were centered around 35 kilograms. A tendency can be detected for the fish to be somewhat smaller to the southward and larger to the northward. An interesting phenomenon is seen in the fact that on days when the average weight of the fish was around 35 kilograms, the catch rates were generally high whereas the catch rates declined very greatly on days when the fish were much larger or smaller than this. According to the reports of the Haruna Maru, very small fish of 10 to 20 kilograms were taken on one or two days at almost regular periods several days apart, and on these days the catch rates were very low. The fishing stations were so close together that they can be quite properly regarded as a single location. The significance of this sort of phenomenon cannot be adequately explained, but it is thought to be worthy of attention both from the biological and the fishing points of view.

The size of the yellowfin in the sea area south of the Equator appears to have been completely different on either side of a boundary line in the vicinity of 6° S. latitude. The fish from the north side of this line did not differ greatly in size from those taken in the vicinity of the Equator, but those taken south of the line had an average weight of about 50 kilograms. As the season at which the data were collected was, of course, the same for this area and for the areas along and north of the Equator, it appears that different age groups occur south of 6° S. latitude and in the vicinity of the Equator. Furthermore, as was noted earlier, south of 6° S. latitude there are wider fluctuations in the catch rates and a more unstable fishing situation than along the Equator or to the north of it.

Although there are these differences in the character of the fishing grounds in different parts of the area, it is recognized that the waters off western Sumatra are excellent fishing grounds during the season when the northeasterly winds are at their strongest. The significance of the area as a fishing ground during the season of southwesterly winds is not clear.

3. Waters off Java (6° to 13° S., 105° to 115° E.)

The sea area between the Sunda Strait and the Lombok Strait is that referred to here as the waters off Java. During the season of southerly winds the sea currents in this area are quite simple, with the current which runs along the south coast of the Lesser Sunda archipelago, which lies immediately to the east of Java, simply continuing to flow westward along the south coast of Java. The velocity of this current is rather high, speeds of 1 knot per hour or more having been recorded. A pronounced current boundary appears running southwestward from the vicinity of the Sunda Strait and the coastal waters of Sumatra to the north of this boundary form a completely distinct water system.

From January through March, when the northerly winds blow continuously, the pattern of the sea currents changes completely and becomes remarkably complex. To describe them in a rough outline, there is a conspicuous current boundary trending generally east and west in the vicinity of 8° to 10° S. latitude, and this boundary turns to the southwestward in the vicinity of Lombok Strait at the eastern extremity of this sea area. On the south side of this boundary the currents flow generally westward. The current coming south off the coast of Sumatra turns and flows to the eastward. The current on the north side of the boundary is pressed in very close to the shores of Java by currents on its south side and its velocity is high although the current itself is extremely narrow. The currents on the south side of the boundary come out of the central part of the southern Indian Ocean flowing to the northeastward, and impinging upon the island of Java they turn to the west. To the east of the current boundary in the vicinity of Lombok Strait, the current flowing north along the west coast of Australia turns to the northeast and thereafter turns eastward to flow along the Lesser Sunda archipelago.

As indicated by the above brief description, during the season when northerly winds predominate, the coastal waters of Java are almost completely cut off from and are under the influence of different currents from the adjacent sea areas to the east and the northwest.

Sea conditions in the season of southerly winds are unknown because there are no data. During the season of prevailing northerlies surface water temperatures in this sea area are not greatly different from those of the west coast waters of Sumatra, but the temperatures at the 50-meter and 200-meter levels seem to be rather markedly lower.

The season of southerly winds is the rainy season in this sea area and the weather is bad and the sea rough. Furthermore, typhoons occur from time to time and it is thought that interference with operations by the weather will be frequent. During the season of northerly winds there is continuous good weather, the sea is extremely calm, and operating should be easy.

Data on past investigations in this sea area are available only from the Hakuyō Maru and the Haruna Maru. Investigations of the Haruna Maru were carried on during December 1933, and the area investigated was limited to the eastern and western extremes of this sea area, that is, the vicinities of the Lombok and Sunda straits. The explorations of the Hakuyō Maru were carried out in June 1926 and were scattered throughout this whole area. These data have been brought together to show the fishing conditions in the waters of Java in the following table.

Table 14.--Fishing conditions in Java waters (Hakuyō Maru, January 1931; Haruna Maru, December 1933)

Vessel	Number of.hooks	Yellowfin		Bigeye		Spearfishes		Tunas and spearfishes		Sharks	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Hakuyō	900	10	1.11	0	0.00	0	0.00	10	1.11	10	1.11
Haruna	8,720	280	3.21	63	0.72	61	0.70	404	4.63	180	2.06
Total	9,620	290	3.03	63	0.65	61	0.63	414	4.30	190	1.97

As the data are not only very scarce but extremely unevenly distributed, there is danger in drawing conclusions on the basis of just these data, however, if the facts shown in the foregoing table are compared with the data from the waters of Sumatra and the Lesser Sunda archipelago (to be discussed below), it may be thought that fishing conditions in Java waters during the season of northerly winds are markedly slack in comparison with adjacent sea areas. Furthermore, as has already been stated, the investigations of the Haruna Maru were confined to the eastern and western extremities of this sea area and therefore it can be seen that fishing was extremely poor off the central part of Java (! sic). The season at which the investigations were carried on coincides with the season of extremely good fishing in the waters off Sumatra. It is consequently difficult to believe that the reason for the marked inferiority of the fishing in this sea area as compared with coastal waters of Sumatra was due to seasonal changes.

The foregoing facts seem to give important indications for the consideration of the distribution of tunas (principally yellowfin) in the Indian Ocean region. The above table makes it appear that the distribution of yellowfin is extremely sparse in the currents which flow into the waters off Java from the central portion of the southern Indian Ocean, or in other words on the offshore side of the current boundary which runs east and west in the vicinity of 8° to 10° S. latitude. Unfortunately, data are very few and a thorough evaluation is impossible, but it is believed that not only yellowfin but bigeye tuna and spearfishes are extremely scarce or almost completely absent in this current.

The investigations of the Haruna Maru showed that, as might have been expected, the fishing picked up somewhat near the eastern and western extremes of this sea area and that here the composition of the catch and the size of the yellowfin, which were the principal element in the catch, agreed well with the catches made in the adjacent Sumatra and Lesser Sunda regions.

From the foregoing it appears that during this season of northerly winds the waters south of Java cannot be expected to have any very great value as tuna fishing grounds.

As there are absolutely no data for the season of southerly winds, we have no way of knowing fishing conditions at this time of year. However, at this season the pattern of the sea currents changes conspicuously, and the current which comes flowing from the Lesser Sunda archipelago on the east continues right along the island of Java to the westward. As will be explained in a later section, fishing in the waters of the Lesser Sundas during the season of southerly winds is quite active, and therefore it is thought that a certain amount of fishing can be anticipated in the waters off Java at this season. However, as has already been stated, unfavorable weather conditions at this time of year must naturally be taken into account.

4 Waters around the Lesser Sunda Islands and Timor (8° to 15° S., 115° to 130° E.)

This sea area of about 350,000 square miles adjoining on the east the area describe in the foregoing section will be characterized as the waters of the Lesser Sunda archipelago and and the island of Timor.

The pattern of the ocean currents from July to September, the season in which the southerly winds are most predominant, is roughly as follows. There is a conspicuous current which comes from the region of the Arafura Sea to the southeast and passes in a westerly direction through this sea area. In the vicinity of the eastern end of the island of Timor this current divides into two branches, one flowing north into the Banda and Flores seas while the other branch continues flowing westward through this sea area. Its velocity is rather high, exceeding 1 knot per hour.

From January to March, when the northerly winds are strong, the pattern of the ocean currents changes completely. A rather strong current which flows northeastward along the west coast of Australia passes away to the eastward along the southern side of the archipelag and along the northern side of the islands there is a current which flows in an easterly direction from the Java Sea area. These two currents of different origins unite in the vicinity of the eastern extremity of this sea area and flow into the Arafura Sea region. As was noted earlier in the section on the waters off Java, a conspicuous current boundary appears running southwestwar from the vicinity of the Lombok Strait at the western extremity of the area, and the water system of this area and those of the waters off Java are completely different.

The color of the water during this season of southerly winds is about II to III on Forel's scale. Transparency also appears to be rather low. Water temperatures are generally low, with 25° C. to 27° C. indicated for the surface layer, 24° C. to 26° C. at 50 meters, and about 20° C. at 100 meters.

During the season of northerly winds the water color is about I to II on the Forel scale, and transparencies range from 25 to 30 meters. Water temperatures are conspicuously higher than during the season of southerly winds, the surface layer having 29° C. or even higher, with 27° C. to 28° C. at 50 meters, and 23° C. to 26° C. at 100 meters, subject to local variations.

The data available for this area are the results of the investigations of the Hakuyō Maru, Haruna Maru, Shōnan Maru, Zuihō Maru (research vessel of the former South Seas government, and the Kiyō Maru (former research vessel of Wakayama Prefecture). Furthermore, the mothership-type tuna fishing operations of the Tōbu Suisan Company also extended into this area, but it is not known what success they had. The following table is a summary of these data.

Table 15.--Fishing conditions in the waters of Timor and the Lesser Sunda Islands

Number of hooks	Yellowfin		Bigeye		Spearfishes		Total tunas and spearfishes		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
48,274	4,032	8.35	161	0.33	322	0.66	4,515	9.37	701	1.45

On the whole the catch rates are, as shown in the foregoing table, rather high and this area is adjudged to be an excellent fishing ground. Data are scarce so it is difficult to make a thoroughgoing comparison, however, the following table compares the fishing situation during the two seasons.

Table 16.--Fishing situation by seasons (waters of Timor and the Lesser Sunda Islands)

Season	Number of hooks	Catch rates
SE winds	46,059	9.43
NW winds	2,215	6.23

Note: Southeasterly winds -- April to September
Northwesterly winds-- October to March

There are very few data available for the season of northwesterly winds so a comparison is difficult, but within the scope of the data the fishing is better during the southeasterlies.

During the season of northwesterly winds the catch rates are at their highest around November, falling off rather sharply from December on. However, as stated earlier, this view is based on scanty data and therefore it is difficult to determine whether or not this is actually the case without further amplifying the data. If there is such a change in the fishing situation, its cause may be thought to be the change in the currents which accompanies the change of season. As we have no data, we know nothing of the changes in the fishing situation after the first part of December.

The yellowfin is the most numerous species in the catch, making up somewhat less than 90 percent of all tunas and spearfishes. The size of the fish appears to be generally larger, most of them weighing about 48 to 55 kilograms. Of course, fish of 20 to 40 kilograms are also taken, but they are proportionately few, and the average weight appears to be between 48 and 50 kilograms. Next to the yellowfin the spearfishes are most numerous, and bigeye tuna are scarce. The catch rates for the species are markedly lower than those of the coastal waters of Sumatra. However, it must be noted that these observations are based on investigations covering an extremely short period of time. The catch rate for sharks is about 1.5, a usual value for the tropics.

As regards the size of the yellowfin and the frequency of occurrence of bigeye tuna and spearfishes this area more closely resembles the adjacent Banda Sea and Flores Sea area to the north than the various sea areas adjoining it on the west. In other words, the size and composition of the catch appear to be close to those found in the Banda Sea area. It is inferred that this sort of phenomenon provides a hint as to the migratory route of the schools which migrate into this area, however, there are no data available which would show this relationship between them concretely. Consequently, it might be thought that this was a mere chance agreement, but a consideration of the pattern of ocean currents makes the foregoing inference seem reasonable. The following table provides a comparison of fishing conditions, catch composition, and the size of yellowfin tuna in this sea area and in the various areas of the Indian Ocean region, the Banda Sea, and the Flores Sea.

This area is sometimes visited by rough weather during the season of southeasterly winds, but in general throughout the year it is calm and it is believed that there is hardly ever any weather such as would interfere with operations. The migrational patterns of the schools are not as yet understood, but within the scope of the investigations which have been made it is probable that this can be called an excellent fishing ground.

Table 17.--Fishing conditions, catch composition, and size of yellowfin tuna compared

Sea area	Catch rate	Percent yellowfin	Percent spearfishes	Percent bigeye	Average weight of yellowfin
Banda Sea and Flores Sea	8.40	89.5	7.2	3.3	48.5
Waters around the Lesser Sundas	9.37	88.6	7.6	3.8	48.0
Waters off Java	4.30	70.0	14.8	15.2	49.6
Waters off Sumatra	10.12	85.9	7.1	8.2	33-35

Notes: 1. The catch rate is the number of tunas and spearfishes caught per hundred hooks.

2. The percentages for tunas and spearfishes are the proportion of those species in the total catch.

Taking a general view of the Indian Ocean region described above, fishing conditions are on the whole better during the season of northerly winds with poorer catches during the season of southerly winds. It is to be regretted that we have very few data for the season of southerly winds, but if it is assumed that the tendency described above can actually be detected, it is deeply interesting to compare it with the situation in the Pacific Ocean areas to be described below.

B. Pacific Ocean Region

Under this heading will be discussed the area from 15° S. latitude to about 43° N. latitude and west of 180° E. longitude. This includes the various seas to the north of the Lesser Sunda Islands. As in the case of the Indian Ocean region, this region has been divided up in accordance with the topography and oceanographic conditions, and an outline of the characteristics of each sea area as a fishing ground will be presented. As there are no standards for subdivision in the central part of the Pacific Ocean, that area will be divided for convenience by latitude and longitude.

1. Molucca Strait, Banda Sea, and Flores Sea (0° to 8° S., 115° to 130° E.)

This sea area is bounded by the Lesser Sunda archipelago, the Molucca Islands, the island of Celebes, and New Guinea. From July to September, that is, during the season when the southerly winds are at their strongest, the current flowing southeast from the Arafura Sea area spreads into the vicinity of the eastern tip of Timor and one of its branches flows westward into the southern part of this sea area. This current again divides southeast of Celebes with one branch advancing northward off the east coast of Celebes, passing through the Molucca Strait, and flowing into the Pacific Ocean. The other branch flows west along the north side of the Lesser Sunda archipelago and enters the Java Sea. Another current of a completely different system flows from the Celebes Sea region through the Macassar Strait and into the western part of the Flores Sea. This current is rather strong, but its effect on fishing is not known.

The ocean currents from January through March, that is, the season at which the northerly winds are at their strongest, are almost completely opposite to the pattern seen from July to September. A current appears flowing eastward from the Java Sea region, and another flows south through the Molucca Strait, the two of them joining southeast of Celebes and flowing into the Arafura Sea region. The current flowing southward through the Macassar Strait from the Celebes Sea region remains as it was in the period from July to September, but its force becomes extremely weak.

The sea is generally calm in this area throughout the year, and it is believed that there will be no interference with operations because of bad weather. As is shown below, the fishing is extraordinarily good and this fact, together with the good climatic conditions, makes this an excellent fishing ground.

The skipjack and tuna fishing grounds of this area have a rather deep relationship to the Japanese. Around 1930 the late Mr. K. Hara, who was at that time a representative in the Diet for Kagoshima Prefecture, settled in Amboina with a number of fishermen from Kagoshima and started a skipjack fishery based there. This party had two fishing vessels which they operated from Menado in the Celebes and other places. This enterprise was affected by the deterioration of the international situation accompanying the Manchurian Incident, which occurred soon after, it was subjected to the opposition of the Netherlands East Indies government, and it finally ended in failure. Before the war, Japanese fishermen based at Menado carried on operations to some extent in the Molucca Strait area.

In this sea area, as in other areas of the south, there is a small-scale fishery carried on by natives using dug-out canoes. In order to supply military needs during World War II a large number of Japanese fishing vessels were mobilized in this region to carry on skipjack and tuna fishing, but no concrete data concerning their success remain. At any rate, this may well be considered a completely untouched fishing ground.

Investigations in this area have been carried on by the Shōnan Maru, Zuihō Maru, and Kiyō Maru. The mothership-type tuna fleet of the Tōbu Suisan Company also operated experimentally in this area. All of the data except those from the mothership-type operation are extremely fragmentary. Consequently there are many points at which these data are inadequate for assessing the value of fishing grounds in this area. The following table presents a summarization of these data.

Table 18.--Fishing conditions in the Banda Sea, Flores Sea, and the Molucca Strait area

Number of hooks used	Yellowfin		Bigeye		Spearfishes		Total tunas and spearfishes		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
81,779	6,228	7.61	225	0.28	510	0.62	6,963	8.40	?	?

Note: This table includes data from mothership-type operations.

As the table shows, rather high values are indicated for the catch rates, and it appears that this area is a very superior tuna longlining ground.

The data are notably uneven in temporal distribution and therefore it is not possible to examine thoroughly the seasonal changes in the fishing situation, however, a comparison is shown in the following table.

Table 19.--Seasonal changes in fishing conditions (Banda Sea, Flores Sea, and Molucca Strait area)

Season	Number of hooks	Catch rate
Southeasterlies	80,089	8.56
Northwesterlies	1,690	7.34

Note: The catch-rates are the combined totals for tunas and spearfishes.

As table 19 shows, fishing is somewhat poorer during the season of northwesterly winds than during the southwesterlies. Very few data are available for the season of northwesterly winds so it is difficult to affirm definitely that fishing is poorer during this season than it is during the southwesterlies. However, it is possible that this table represents accurately the seasonal changes in fishing conditions in this area because the same trends have been demonstrated (see table 16) for the seasonal changes in fishing in the Lesser Sunda archipelago area. (Translator's note: the discussion of seasonal winds in this paragraph does not check with the wind directions given in table 19, which shows a season of northwesterly and a season of southeasterly winds. Available references indicate that the designations used in the table are probably correct and that the southerly seasonal winds in this region actually blow from the southeast.)

Looking at the records of the yellowfin sizes, it appears that in general large fish predominate, with the average weight 48.5 kilograms. Catch rates for bigeye tuna and spearfishes are low, and it appears that bigeye are particularly scarce. The size of the yellowfin and the composition of the catch differ widely from those found in the adjacent Celebes Sea to the north and in the western part of the Pacific, while, as shown in table 17, they bear a remarkably close resemblance to the adjacent waters of the Lesser Sunda Islands. Such phenomena may be thought quite natural from a geographical point of view, and they may further be thought to give some very interesting hints as to the migratory paths of the schools which come into this sea area.

The fact that the size of the yellowfin is generally large, and the fact that they are present throughout the year with little change in density of occurrence are considered to indicate that this sea area may have an important significance in connection with the propagation of the yellowfin. However, nothing concrete has as yet been reported from this sea area concerning their spawning.

This sea area is not only, as stated above, an extraordinarily good tuna longlining ground, but it also appears to present various important problems from the point of view of yellowfin distribution and migrational routes as well as from the standpoint of ecology. In the same sense, the series of sea areas to the north--the Celebes Sea, Sulu Sea, and South China Sea--all having the character of enclosed basins, are thought to be all worthy of attention.

2. Celebes Sea

This sea area is inclosed by Celebes, Borneo, the Sulu archipelago, and Mindanao. To the east it connects with the western Pacific Ocean through the strait between Celebes and Mindanao, on the north with the Sulu Sea across the Sulu archipelago, and on the south with the Flores Sea region by way of Macassar Strait.

From July to September, the season in which the southerly winds predominate, there is a strong current flowing to the southwestward across the central part of this sea area from the strait between Sangi Island and Mindanao at the eastern end of the area. After flowing across this sea area, this current passes into the Flores Sea by way of the Strait of Macassar. This is a current of considerable force, but its strength is said to be affected by the tide. There is another weaker current flowing along the northern coast of Celebes in a direction generally opposite that of the current already mentioned. Another weak current appears in the northern part of the area flowing northward along the coast of Mindanao into the Sulu Sea. There is a weak current flowing in the opposite direction to this southward along the coast of Borneo into the Sulu Sea. Consequently, taking this sea area as a whole, it can be considered that there is a strong current flowing across the central portion from northeast to southwest, with other currents flowing generally in a counterclockwise direction around the edges.

As for water temperatures, they are 28° C. to 29° C. in the surface layer, and 27° C. to 29° C. at 50 meters. The water temperature at the 100-meter level differs markedly from one place to another, ranging from 21° C. to 26° C. with an average value of about 24° C. Water color is most often I to II on the Forel scale and transparency is high, 25 to 40 meters having been recorded.

From January through March, the season when the northerly winds are strongest, the current which flowed from northeast to southwest through the central portion of the area during the season of southwesterly winds is remarkably reduced in strength and it becomes impossible to find any conspicuous current throughout the area. Only the current flowing south along the island of Borneo from the Sulu Sea increases somewhat in strength.

Surface water temperature is 27° C. to 28° C., a drop of about 1° as compared to the season of southwesterlies. The 50-meter level, on the contrary, has temperatures about 1° higher and consequently shows temperatures somewhat higher than those of the surface water. Water temperatures at 100 meters are also in general slightly higher than during the southwesterlies, with values of 24° C. to 26° C. In some localities a rather pronounced thermocline appears sometimes in the vicinity of the 100-meter level. The color of the water in the central portion is generally I on Forel's scale with the frequency of II to III increasing toward the borders of the area. Consequently transparency is high in the central portion with values of around 30 meters, and with smaller values on the edges of the area.

During this season of northerly winds rather strong winds sometimes blow continuously, but it appears they would not be sufficient to interfere with operations. During the season of southerly winds the sea is generally extremely calm.

This sea area had already been developed as a fishing ground before the war. Some of the large fishing vessels based at Takao in Formosa occasionally operated in this area. Boats of the Borneo Fishing Company (operated by Japanese) based at Shamil Island in British North Borneo and of the Filipino-Japanese Sea Food Corporation based at Zamboanga were active in the area. The boats based at Takao were all longliners, but the others fished mainly with pole and line for skipjack and small yellowfin. Investigations have been carried on in this sea area by the Shōnan Maru and the Takao Maru (research vessel of the former Takao Province). The mothership-type tuna fleet of the Tōbu Suisan Company also operated experimentally in this area. An exploratory fleet from Kagoshima Prefecture also fished in this area with the objective of developing the skipjack pole and line fishery. The following table summarizes the data from these investigations.

For most of the data there are no records broken down by species so the catch rates for each species are not known. In the cases where such data are recorded, it appears that the catch of bigeye tuna is extraordinarily small. However, spearfishes (mainly white marlin) are extremely abundant, the catch rates averaging 2.37. Whether these high spearfish catch rates represent normal conditions in this sea area or whether they are a phenomenon which appears only at certain seasons cannot be determined because of the paucity of data. At any rate it is certain that the spearfishes are quite abundant. It is also certain, of course, that their catch rates show seasonal fluctuations.

Table 20.--Fishing conditions in the Celebes Sea

Number of hooks	Yellowfin		Bigeye		Spearfishes		Total		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
157, 156	?	?	?	?	?	?	6, 553	4. 16	?	?

The most numerous species in the catch is naturally the yellowfin. The density of distribution of the yellowfin appears to undergo large seasonal fluctuations as can be inferred from the following table.

Table 21.--Fishing conditions by season (Celebes Sea)

Season	Number of hooks	Number of fish	Catch rate
April - Sept.	7, 493	714	9. 53
Oct. - March	146, 662	5, 839	4. 06

Notes: (1) Catch and catch rate figures represent the total of tunas and spearfishes.

(2) April to September is the season of southerly winds, October to March that of northerly winds.

As the number of hooks fished during the season of southerly winds is very small, the numerical values for the seasonal changes in fishing conditions shown in the above table cannot perhaps be said to be accurate ones. However, it can be seen at any rate that within the scope of this table the seasonal changes in fishing conditions are extremely marked. The table indicates that the catch rates during the season of southerly winds are more than twice as much as those during the season of northerly winds, and it goes without saying that the greatest factor in this change in catch rates is an increase in yellowfin.

In addition to the surveys mentioned above, the Kōhō Maru of the Kōchi Prefecture Fisheries Experiment Station also investigated this sea area. This work was done in November and December of 1931. It is not possible to calculate the catch rate because the construction of the fishing gear employed has not been reported, but during the period mentioned, the Kōhō Maru fished a total of 721 baskets and took a total of tunas and spearfishes amounting to 341 fish. This is a catch of more than 47 fish per hundred baskets. If we assume that there were six hooks per basket, the catch rate would be about 8. 0, a rather high figure.

There are few records concerning the size of the yellowfin and the details are not known. Consideration of a certain amount of data makes it appear that large fish are generally more numerous in the season of northerly winds with slightly smaller ones predominating during the season of southerly winds. The average weight for the whole year is about 44 kilograms, rather markedly smaller than the fish of the Flores Sea region and considerably larger than those from the equatorial Pacific. It is an interesting fact that if we compare the condition factor[5] for yellowfin taken at the height of the season of northerly winds, those from the Celebes Sea give markedly lower values than those from the East Philippine Sea and the Sulu Sea (see Nakamura[6]).

The Shōnan Maru carried on its investigations using a special kind of fishing gear with a float attached to each branch line. The object of using this sort of gear was to determine accurately the fishing level (or swimming level) for the tunas and spearfishes. With the gear commonly used it is not easy to determine the depth at which the hooks are hanging, but with the Shōnan Maru's gear the position of the hook could not be deeper than "length of branch line plus length of float line," so that the limit at one extreme was always given.

Looking at the results of investigations made with this sort of gear, we see that there are rather conspicuous differences in catch rates between branch lines. In one remarkable example the total length of the float line and branch line was 160 meters and a considerable catch was made, the catch rate being 6.0. In general the catch rates were highest where the total length of float line and branch line was about 100 meters, but rather high catch rates were also obtained where the total length was about 50 meters, which appears to indicate that there are two fishing levels (see Nakamura[7]).

It is considered that the reason for the existence of two fishing levels is that the catch of spearfishes in this sea area is fairly great and that the spearfish catch rates show high values at about the 50-meter level while the yellowfin are taken in the greatest numbers at about the 100-meter level. The following table shows one example.

Table 22.--Fishing conditions at different depths (Celebes Sea, July-August 1934, Shōnan Maru)

Depth (meters)	Tunas		Spearfishes	
	Number of fish	Catch rate	Number of fish	Catch rate
45	65	6.25	26	2.50
76	182	8.76	36	1.75
106	205	9.86	20	0.95

Note: (1) Depths are length of branch line plus length of float line.

As was noted earlier, it appears that fishing conditions in this sea area vary markedly with the season. The local variations in the fishing conditions are not well understood, but it appears that they also exist. If the season and the locality are suitably taken into account as regards the construction of fishing gear, it is thought that this sea area will be an excellent tuna longlining ground. It has already been noted that from the standpoint of weather it offers superior conditions.

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[5] Condition factor is $\frac{W}{L^3}$ x 1000; L = body length, W = weight.

[6] Nakamura, Hiroshi. Tuna Fishery Resources and Fishing Grounds, Fisheries Quarterly, II, December 1949.

[7] Nakamura, Hiroshi. The Tunas and Their Fishery, Takeuchi Shōbo, 1949.

3. Sulu Sea

This body of water adjoins the Celebes Sea to the northward beyond the Sulu archipelago and is surrounded by Borneo, Palawan, Mindanao, and others of the Philippine Islands. To the northward it connects with the South China Sea beyond the island of Palawan. During the season of southwesterly winds a rather strong current, which flows northward from the Celebes Sea through this sea area into the South China Sea, appears somewhat east of the middle of this area. It is said that on the western side near Borneo, there is a very weak current flowing southward.

There are no data at all for this season so nothing can be said concerning the water temperatures and other hydrographic conditions, but it is assumed that they are not greatly different from those of the Celebes Sea region. During the season of northeasterly winds on the whole no very conspicuous currents can be seen in this area although there is a weak current around the center of the area trending southwest. It is said also that taking the area as a whole there is a weak circular current flowing in a counter-clockwise direction.

Water temperatures and other conditions during the northeasterlies are in outline as follows. Around October surface temperatures are 28° C. to 29° C., temperatures at the 50-meter level differ little from the surface, while the 100-meter level shows temperatures of 24° C. to 26° C. Water colors mostly of I to II on Forel's scale have been observed, and the transparency is high, figures of 30 meters or more being attained. Around February and March the water temperatures are markedly lower, with figures of 26° C. to 26.5° C. in the surface layer, about 26° C. at the 50-meter level, and 20° C. to 22° C. at 100 meters. At about this time a conspicuous zone of cold water appears centered on the line of 120° E. longitude about the middle of this sea area. This water mass shows temperatures about 2° lower than the surrounding waters. At the same time the water color changes greatly, III to IV on Forel's scale being reported in the majority of cases. Consequently, the transparency is greatly lowered, with values of 20 meters or less reported in most cases.

During the season of southwesterlies the sea is always calm and operations would be extremely easy. At the season when the northeast winds are strongest the area is visited from time to time by high winds and high seas making it difficult occasionally for small fishing vessels to operate.

This area has been for a good many years within the operating radius of fishing boats based at Takao. Fishing operations have also been carried on here by boats of the Borneo Fisheries Company based at Shamil, as mentioned in the section on the Celebes Sea, and boats of the Sea Food Corporation based at Zamboanga. Boats from Takao for the most part fish this region from September to the middle of October, taking principally yellowfin along with black marlin, white marlin, and striped marlin. It appears that a fairly considerable catch of broadbill is also made at this season. Ordinarily once this season is passed there are almost no fishing boats operating in this area, most of them appearing to turn to operations in the South China Sea. As will be explained in a later section on the South China Sea, the main fishing season in that area is the season of northeasterly winds from October on. The normal situation in most years is for fishing to be most active in the early part of the season in the waters adjoining the Sulu Sea.

When we put together the facts that fishing is at its most active in the Celebes Sea from July to September, that the greatest number of fishing vessels operate in the Sulu Sea in September and October, and that in the South China Sea adjoining to the north fishing begins from October on, beginning in the areas adjacent to the Sulu Sea, it may be thought that in this connected series of sea areas the schools move gradually from south to north. However, if we leave aside such observations based on fishing conditions, and consider the size of the yellowfin, it appears that we can get results which deny the existence of such a migratory route. That is, if we look at the condition factor of the yellowfin taken in these various sea areas at the same season, despite the fact that no conspicuous differences in size composition of the catch can be seen, the condition factor values vary widely, with the highest figures in the Sulu Sea, the lowest values for the Celebes Sea, and with the South China Sea in between.

Data for this sea area have been reported by the Shōnan Maru, Takao Maru, Kōhō Maru, and the Daijin Maru and Sasshū Maru from Kagoshima Prefecture. These surveys and commercial operations have been limited to the season of the northeasterly winds, so fishing conditions during the southwesterlies are completely unknown. Furthermore, there are no records of the fishing situation by species so no catch rates can be shown except for tunas and spearfishes combined. In the reports of the Kōhō Maru and the Sasshū Maru the number of hooks is not indicated, only the number of baskets of gear having been recorded. The following table shows the catch rates based on those data for which the number of hooks is known.

Table 23.--Fishing conditions in the Sulu Sea

Number of hooks	Number of fish	Catch rate
9,160	619	6.08

The catch rate is slightly greater than 6.0, better than that for the South China Sea, which will be discussed later, and even surpassing the year-round average for the Celebes Sea. Fishing conditions encountered by the Kōhō Maru and Sasshū Maru are shown in the following table.

Table 24.--Fishing conditions in the Sulu Sea (according to the Kōhō Maru and Sasshū Maru)

Number of baskets	Number of fish	Fish per 100 baskets
2,646	837	31.6

If we assume that there were 6 hooks per basket, the catch rate would be slightly less than 5.3.

We have no detailed knowledge of seasonal changes in fishing conditions, but it appears that fishing is good from around the end of the season of southwesterlies through the early part of the northeasterlies. Thereafter the fishing gradually falls off as the days pass and it appears that by February and March the catch rates fall to about 4.0 to 4.5, values not greatly different from those of the Celebes Sea region. At that time, as has already been remarked, a cold water mass appears in the central part of this sea area and within this cold water mass fishing seems to be very poor, with almost no catches made.

As already stated, the fishing situation for different species is not known, but yellowfin are the principal catch. It appears that spearfishes also occupy a rather large proportion of the catch, but the percentage cannot be shown because no data are available. Broadbill are extremely scarce and there has been as yet no report of albacore.

This sea area is of small extent and cannot accommodate a large number of fishing vessels at the same time. However, at some seasons it has rather high catch rates and probably can be said to be a good fishing ground. If it were possible to have a base in the Philippine or in northeastern Borneo, the fishery would be even more profitable. There may be some interference from the weather, but it is not of very great importance and if a base were availabl in this region, it would be possible to operate with quite small fishing vessels.

4. South China Sea

This sea area is bounded by the continent and the islands of Borneo, Palawan, Luzon and Formosa. On the south it connects with the Sulu Sea and on the east through the Bashi Strait with the Pacific Ocean. On the west it is connected with the Gulf of Siam. Along the Asiatic mainland the so-called continental shelf is developed, but the central portion is deep and in the southern portion there are reef areas.

The pattern of the currents from July through September, when the southwest winds are at their height, is as follows. In the western part of this area there is a current flowing fro the Java Sea region to the waters off Annam. This current, which is quite strong, divides into two branches off Cochin China. One branch flows to the northeast along the northwest side of thi area, while the other flows in a circle clockwise. At the eastern side there is a current flowing north along the island of Luzon, part of which flows into the Pacific through the Bashi Strait and joins the Kuroshio, while another part flows north through the Formosa Strait. There is a weak cold current along the continental coast, which submerges and flows to the south.

From July to September water temperatures are about 28° C. to 29° C. at the surface, and about 26° C. at 50 meters. At the 100-meter level there is a conspicuous difference between the continental side and the portion east of the middle of the area. The side near the continent has low temperatures of 11° C. to 17° C. with a wide range of variation. From the middle of the area east, particularly along Luzon, temperatures are high, with values of 22° C. to 24° C. Water color for the most part is I to II on Forel's scale with consequent high transparencies of about 30 to 38 meters.

From January to March, when northeast winds predominate, the currents are roughly opposite to the pattern for the southwest monsoon. There is a strong current flowing southward along the continent, and it is said that throughout the area as a whole the circulation is in a counterclockwise direction, but it appears to be rather complex. The current flowing north along Luzon is weakened but continues in existence.

Surface water temperatures are 25° C. to 26° C. over broad areas, but there are also places with about 23° C. Temperatures at the 50-meter level are for the most part about 23° C., with values of 17° C. to 18° C. at some localities. At the 100-meter level water temperatures average about 19° C., with the lowest temperature recorded being between 14° C. and 15° C. In the general view the distribution of water temperatures is clearly high in the east and low in the west, with generally high temperatures along the Luzon side and conspicuously lower temperatures off the continent. A very conspicuous zone of low water temperatures appears in the central part of this sea area, with temperatures 2° C. to 3° C. lower than the surrounding waters. The extent and position of this cold water zone appear to vary with the season and from year to year, but fishing is generally very poor within this zone, showing a trend completely identical with that for the Sulu Sea. Transparencies also show a tendency to be high in the east and low to the westward, the water color off Luzon being in most cases I to II on the Forel scale, with transparencies of 30 to 40 meters being most common. On the continental side observations of water colors of II to III are most numerous, with transparencies in most cases of 20 to 30 meters.

During the season of southwesterly winds the sea is generally very calm. However, in the typhoon season the paths of the storms occasionally cross this sea area. Caution is necessary, particularly toward the beginning and end of the typhoon season, for at this time many typhoons cross the northern part of the area. During the season of northeasterlies strong winds blow continuously, the seas are high, and it is occasionally difficult for fishing boats to operate. Wind and seas are particularly high off Annam, making operations by small boats difficult. The waters off Luzon are generally calm.

The history of the development of the tuna longline fishery in this area is so closely tied up with that of the tuna fishery at Takao that they may be said to be the same thing. The tuna longline fishery based at Takao, which started around 1913 under the aegis of the former Formosa Government-General, developed year after year with the South China Sea as its principal fishing ground. At first sailing vessels were used, but very soon all the boats were powered, beginning with vessels of about 20 horsepower and gradually increasing in size with the years until many vessels of 100 tons and 200 horsepower were being constructed. In 1936 the number of vessels operating had increased to about 300. The fishing grounds were gradually extended to the southward from the southern portion of the Formosa Strait and the whole South China Sea came within the operating area. The boats then began going farther into the Sulu Sea, Celebes Sea, and East Philippine Sea regions, and before the war the catch had surpassed the value of 15 million yen per year.

The fishing season is for the most part during the season of northeasterly winds. Vessels which had been docked and overhauled during the typhoon season gradually go into operation from the latter part of September on and ordinarily continue fishing until about May of the following year. However, around June to August a fishery for sailfish with the gear called barennawa is carried on, so even during the typhoon season fishing does not stop altogether. Beginning in 1935 there was a rapid development of the black tuna fishery and its fishing season was from March to early June. As it became known that many black marlin could be taken during the southwesterlies the latter years of the Japanese occupation of Formosa saw longline fishing carried on almost throughout the year.

The following is a general outline of fishing seasons and the fishing situation in the South China Sea. At the beginning of the season around September some catches, principally of yellowfin, were made in the southeastern portion of the area, that is, the part adjacent to the Sulu Sea, and with the passage of time fishing gradually became active in the vicinity of Steward Bank and Macclesfield Bank, after which the fishing suddenly became good all over the whole area. However, around January to March, when a conspicuous cold water zone appears in the central portion of the area, as already noted, fishing becomes generally poorer in this central area. Toward the end of the fishing season the center of the fishing grounds shifts from the vicinity of Dangerous Ground to the waters off Cochin China and Annam, and at this time the fishing for spearfishes becomes active from this area to the vicinity of Hainan I.

The principal species in the catch is the yellowfin. Data from investigations covering the whole year indicate that about 90 percent of the fish in the total tuna and spearfish catch of the longline fishery in this region are yellowfin, the remaining 10 percent being bigeye tuna (?) and spearfishes. However, this is in the overall view and as was noted earlier, the situation is completely different as regards the so-called barennawa, which fishes especially for bigeye tuna and sailfish or in the case of the fishery between the waters of Annam and the Hainan I. region, where spearfishes are the main objective. The foregoing is the situation which obtained before the development of the black tuna fishery in recent years. The main component of the catch during the black tuna season was, it goes without saying, black tuna. In recent years the black marlin has followed the black tuna in becoming abundant in the catch, and taking Formosa as a whole it appears that in recent years the number of tunas and the number of spearfishes in the catch have been almost equal (see table 7).

The first captures of black tuna in this area were in 1935. Before that year there are no records of this species being taken, but it is questionable whether they were completely absent. Questioning of fishermen at Takao at that time revealed that every year at about the same season some large fish had been biting on the hooks and breaking the branch lines so that year they strengthened the fishing gear and for the first time took black tuna. Judging from the manner in which young black tuna appear from summer to autumn along the coast of Japan, it has been believed for many years that there was ample possibility of the occurrence of this species in this area.

A tendency has been seen for the black tuna season in the South China Sea area to become gradually earlier with the passage of the years, but in ordinary years the species begins to be taken around the middle or latter part of March and the fishery gradually becomes more active with the passage of time, reaching its peak during approximately 1 month from the middle of April to the middle of May. Thereafter the fishing gradually falls off until almost no black tuna are taken in the early part of June. Around the end of the fishing season in most years some fish are caught east of Formosa and in the Ryūkyū area, from which it is inferred that there is a rapid movement of the schools to the northward.

The first catch is often made along the 100-fathom line in the vicinity of Platas Shoal, after which it is said the fishing gradually shifts to the eastward. During the first 2 or 3 years after this fishery was started the grounds were confined to that part of the China Sea west of the Bashi Strait and it was thought that in general the fish did not occur south of Lingayen Gulf (16° N. latitude). However, with the passage of years the fishing grounds were extended to the eastward and it was discovered that there were superior fishing grounds in the Pacific Ocean east of the Bataan and Babuyan islands, while at the same time the grounds were extended to the southward along the east coast of Luzon until all of the waters east of Luzon north of 15° N. latitude became fishing grounds.

There are almost no data from surveys by research vessels in the South China Sea and the East Philippine Sea, but catch rates recorded by the author aboard commercial vessels and those obtained from data supplied by commercial vessels to the former Taiwan Government-General show catch rates of 2.0 to 3.0. As yellowfin and spearfishes were taken in addition to black tuna, the combined catch rate for tunas and spearfishes was 6.0 to 7.0. Accordingly it may be thought that the longline fishery in the area where black tuna were the main object was rather advantageous financially. Before the war fishing vessels from Kagoshima, Kōchi, and other prefectures operated in May and June from the waters east of Formosa to the coastal waters of the Ryūkyū Islands and produced a considerable catch. Since the war considerable fishing has continued in this region.

The black tuna of the South China Sea region are in general large in size, most of those taken around the beginning of the season weighing 300 kilograms or more. Toward the end of the season the fish gradually becomes smaller, but even so examples of fish weighing less than 200 kilograms are rare in the catch. It bears no direct relationship to the fishery, but it is known that at this season in this sea area the black tuna are spawning.

This fishery was almost completely discontinued in the latter part of World War II, and the post-war situation is completely unknown, so nothing can be said concerning the present state of the fishery. It appears possible, however, to discern a number of phenomena which make one wonder whether the black tuna fishery in this area may not be gradually declining. What is meant here by a decline in the fishery is not due to any human cause, such as the operation of commercial fishing vessels, but to a change in the migrational pattern of the black tuna. Investigations in this sea area by the Shōnan Maru, Takao Maru, Zunan Maru (former research vessel of the Okinawa Prefecture Fisheries Experiment Station), Kiyō Maru, the Gini Maru (research vessel of Mie Prefecture), Kōhō Maru, and Haruna Maru have been reported. Among these are some data which it is already impossible to obtain, but those which remain may be summarized to show the fishing conditions in this sea area as given in table 25.

Table 25.--Fishing conditions in the South China Sea

Number of hooks	Tunas and spearfishes		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate
119,074	5,453	4.58	871	0.73

In most of the data there are no records of fishing conditions by species, so the tunas and spearfishes have unavoidably been lumped together in this table. The overall catch rate is, as shown in the table, 4.58. This value is somewhat below that for the Sulu Sea, and somewhat better than that for the Celebes Sea. Consequently, taking distance into consideration, for vessels based at Takao of these three sea areas the South China Sea is thought to have the greatest value as a fishing ground. It should be thoroughly noted, however, that in this observation no account whatever is taken of seasonal changes in the fishing situation.

As very few data are available for the season of southwesterly winds, it is difficult to compare fishing conditions in this season with those during the northeasterlies. However, in recent years the spearfish catch has been rather large from May to August. Seasonal changes in the density of occurrence of the various species will be discussed later in the section headed "Distribution of the Tunas as Shown by Catch Rates."

In the early days of its development, the tuna longline fishery based at Takao used as bait the ginkagami (poito in Formosan), Mene maculata. For this reason the abundance or scarcity of the ginkagami directly controlled the operation of the tuna longline fishery. However, beginning around the end of the Taishō Era (1924) the sabahi, Chanos chanos, gradually came into use and in this way the greatest weakness of the fishery, that is, the bait supply, was taken care of. As is generally known, the sabahi is a fish which is cultured in ponds in southern Formosa. As this fish is cultivated over a broad area not only in Formosa but in the Philippines, Celebes, and Java, it is thought to have an important significance as bait for this fishery in the southern areas, where tuna longline bait is generally scarce. It may be possible to solve the bait problem of the tuna longline fishery based in the various southern areas by utilizing this fish. Tuna longline fishermen may, by a multiple operation, be able to carry on at the same time the culture of the sabahi and thus make an even more advantageous solution of their bait problems.

As was stated earlier, there are a number of shortcomings from the standpoint of weather because of the passage of typhoons and the strength of the seasonal northeast winds, but the South China Sea can probably be said to be a superior fishing ground. The value of this sea area as a fishing ground would be enhanced particularly if it were possible to get a land base somewhere around its shores.

5. Waters around New Guinea and the Solomon Islands (0° to 15° S., 130° to 170° E.)

That part of the Banda Sea extending from New Guinea to 130° E. longitude has already been discussed in the section on the Banda and Flores seas and therefore will be omitted here.

From January to March, when northwesterly winds prevail, the waters off the north coast of New Guinea have a rather conspicuous current flowing from northwest to southeast. This current impinges upon the island of New Britain, after which it does not appear to maintain a fixed direction of flow. On the east side of New Britain there is a current flowing roughly from northwest to southeast, and in the southern portion of the Solomon Islands there is a current flowing generally southward. Another current flows generally northward along the west side of the Solomon archipelago. However, these currents are all extremely weak and the islands make them remarkably complex.

Water temperatures from the Equator to 5° S. latitude are 27° C. to 29° C. at the surface, 24° C. to 28.5° C. at the 50-meter level, and 16° C. to 26° C. at 100 meters. They vary greatly from one locality to another. Farther to the south the temperatures are somewhat lower, but they still appear to be subject to wide local variation. Water color and transparency also show marked local fluctuations.

From July to September, the season when the southeast winds are strong, the currents generally flow from east to west and their strength becomes more marked. Under the influence of the topography the direction of the currents varies somewhat from place to place, but throughout the sea area as a whole the currents clearly flow from east to west.

Few data are available to show the water temperatures and other hydrographic conditions, and it is impossible to examine them in detail, however, in the vicinity of the Equator the temperatures appear to be about 28° C. to 29° C. at the surface, about 28° C. at 50 meters, and 20° C. to 26° C. at the 100-meter level. It is deduced that in the southern part of the Solomons area the temperatures will be somewhat lower than during the season of northwesterly winds.

It appears that during the season of northwesterly winds the area off the north coast of New Guinea has rather high winds and rough seas, and operating may be difficult at times. The seas of the Solomon Islands region are generally calm. It seems that during the season in which the southeasterly winds prevail, the wind and sea in the Solomon Islands region are high and from time to time fierce squalls visit the area so that care is probably necessary in conducting fishing operations. Off the north coast of New Guinea the sea is extremely calm.

Data for this area are principally those reported by the Hakuyō Maru. Some investigations were also carried on by the Zuihō Maru and the Kiyō Maru. The following table summarizes these data.

Table 26.--Fishing conditions in the waters around New Guinea and the Solomon Islands

	Yellowfin		Bigeye		Spearfishes		Tunas and spearfishes		Sharks	
Number of hooks	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
31,992	1,674	5.24	97	0.30	312	0.66	1,866	5.90	558	1.74

The overall catch rate is 5.9, a rather high figure. The above table also includes some data from the Banda Sea area east of 130° E. longitude. It can hardly be considered reasonable to discuss simultaneously two completely different sea areas. Consequently, the data of the above table have been divided into those for the Banda Sea area and those for the Pacific region and are presented in the following two tables.

Table 27.--Fishing conditions in waters off New Guinea (Banda Sea side)

Number of hooks	Yellowfin		Bigeye		Spearfish		Total		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
9,600	1,016	10.58	32	0.33	22	0.23	1,070	11.15	64	0.67

Table 28.--Fishing conditions in waters off New Guinea and the Solomon Islands (Pacific Ocean side)

Number of hooks	Yellowfin		Bigeye		Spearfish		Total		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
22,392	658	2.94	65	0.29	190	0.85	913	4.08	494	2.21

As tables 27 and 28 show, there are conspicuous differences between the catch rates in the two areas. And not only can differences in the fishing conditions be detected, but there are also conspicuous differences in the composition of the catch.

The Banda Sea catch rates are remarkably high, and the composition of the catch is similar to that of the Banda Sea and the Flores Sea already described (see table 18). On the Pacific Ocean side the catch rates are low and yellowfin are scarce while the spearfishes are much more numerous. There is also a marked increase in the number of sharks on the Pacific Ocean side.

The fishing situation in the waters adjacent to the Solomon Islands shows a tendency for a decline in the number of yellowfin in the catch as one goes south from the vicinity of the Equator. This trend is just like that which can be seen in the northern hemisphere. It appears that there is also a tendency for the catch of sharks and spearfishes to increase as the operations come closer to islands. Considered seasonally, it appears that fishing is somewhat poorer during the northwesterlies than during the season of southeasterly winds, but it is difficult to make a thorough-going comparison because of the paucity of data.

Before the war vessels based at Misaki were crossing the Equator to fish as far away as the north coastal waters of New Guinea. During the war, just as in other areas, a large number of vessels appear to have been active in this region with the object of supplying the military forces, but no data remain from these operations. At present no boats from Japan are fishing in the area and as the tuna fishery is completely undeveloped in these islands, it is believed that these waters are being completely neglected as fishing grounds. Seasonal variations in the fishing situation are as yet not well known, but it is thought that there is ample possibility that this sea area can afford superior fishing grounds at some seasons.

6. Southern part of former South Seas Mandate (0 to 10° N., 130° to 170° E.)

The current systems of this area from south to north are the South Equatorial Current, the Equatorial Countercurrent, and the North Equatorial Current. The boundary betwe the South Equatorial Current and the Equatorial Countercurrent is from the vicinity of the Equator to about 3° N. latitude and the boundary between the Equatorial Countercurrent and the North Equatorial Current is between 5° and 8° N. latitude. The boundaries between these currents are not straight lines but change with the topography and the season, however, in general they parallel the parallels of latitude. They are generally pushed to the southward during the season of northeast winds and tend more or less northward during the season of southwesterly winds. The pattern of the current in the vicinity of 130° E. longitude, that is, at the western extremity of this area, is affected by the proximity to land and is remarkably complex.

The following table shows monthly changes in water temperatures based on data from observations made at fixed stations by the former South Seas Government-General Fisheries Experiment Station in the vicinity of 7° 10' N., 134° 30' E.

Table 29.--Water temperatures for each month
(7° 10' N., 134° 30' E.)

Depth in meters	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
0	28.56	28.15	28.40	28.82	29.35	29.31	29.14	28.85	29.13	29.43	29.32	29.05
50	27.50	27.54	28.08	28.61	28.80	28.55	29.07	28.67	29.06	29.12	28.93	28.51
100	23.31	22.48	24.45	25.92	24.93	25.15	24.92	26.12	25.64	26.04	25.37	23.44

Surface water temperatures are high in May and June and in October and November, low in February and March, and they also drop somewhat in August. The 50-meter level shows high temperatures above 29° C. in July and September and October, while in January and February the temperatures at this level are lowered to 27.5° C. At the 100-meter level the water temperature rises above 26° C. in August and in October, and in February it reaches its lowest point with readings between 22° C. and 23° C. Water color is I or II on Forel's scale and transparencies are 30 to 40 meters.

During the season of southerly winds the sea is extremely calm, and this is called the calm season. During the season of northeasterly winds the wind and waves sometimes rise rather high and it appears that at times difficulty is experienced in fishing.

After the South Sea islands in this region became a Japanese mandate, attention was first given to the skipjack grounds and efforts were made to develop them. As a result skipjack fisheries were fairly well developed on the grounds around the coasts of the various islands. However, the bait problem was not solved and the fishery was always in difficulties because of the uncertain bait supply and economic factors such as the falling price of the product (mainly dried skipjack).

The former South Seas Government-General, with the support of the Ministry of Agriculture and Forestry, undertook the investigation and development of tuna longlining grounds in this region, but for a long time they attracted very little attention. It appears that the reason the investigations had poor results at first and that it consequently was not understood that there were excellent fishing grounds in this region was mainly the unsuitable construction of the fishing gear. The gear in use at that time was exactly the same in construction as that used in Japanese coastal waters. Consequently it was unsuited to the markedly different environment afforded by the waters of this area; it is said that the branch lines were too short and did not reach the level at which the tunas swim.

Gradually measures were taken to improve the methods of investigation, and it was made clear that this region affords excellent fishing grounds, which were thus finally brought to the attention of the industry. The direct motive for the sudden development of the fishing grounds of this region was the full load of yellowfin brought back in 1936 by the Hidekichi Maru (90 tons) based at Misaki in Kanagawa prefecture. Stimulated by this, the large fishing boats based at Misaki began competing to fish on these grounds. Some mention of the history of this fishery has already been made in preceding chapters.

Fishing ground surveys and fishing experiments in this region were carried on by the former South Seas Government-General Fisheries Experiment Station with its research vessels Hakuō Maru and Zuihō Maru. Later when this region was being exploited as a longlining ground for tuna, principally yellowfin, a large number of prefectural research vessels also operated there and, as the following table shows, the data from their researches are quite abundant.

Table 30.--Fishing conditions in the southern portion of the former South Seas Mandate (0° - 10° N., 130° - 170° E.)

	Yellowfin		Bigeye		Spearfishes		Total	
Number of hooks	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
647,689	21,870	3.38	3,285	0.51	4,752	0.73	29,907	4.62

Note: The figure for yellowfin also includes 142 albacore.

The situation as regards sharks is not clear because there are many omissions in the data. However, calculations based on considerable material give a catch rate of about 1.5 .

As for the composition of the catch of tunas and spearfishes, yellowfin were most numerous forming slightly under 74 percent of the whole. Spearfishes were slightly more than 15 percent and bigeye tuna were 11 percent. In addition a very small number of albacore were caught, amounting to about 0.6 percent of the yellowfin. On the whole the catch rates in this area are somewhat better than in the Pacific coastal waters of New Guinea or the Solomon Islands, and not greatly different from those of the South China Sea or the Celebes Sea.

There appear to be fairly conspicuous differences in the fishing conditions in different parts of this region. The following table shows a comparison of fishing conditions north and south of the line of 5° N. latitude.

Table 31.--Comparison of fishing conditions on either side of the line of 5° N. latitude (southern part of former South Seas Mandate)

Area	Number of hooks	Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
0° - 5° N.	417,851	16,706	3.99	2,059	0.49	2,928	0.70	21,819	5.22
5° -10° N.	229,838	5,022	2.19	1,226	0.53	1,824	0.79	8,088	3.52

Note: Longitude is not taken into consideration in this table.

The above table shows the existence of a rather conspicuous difference in fishing conditions in the two areas. However, the reason for this difference is the difference in the catch rate for yellowfin. The catch rates for bigeye tuna and spearfishes do not differ greatly between the two areas, and, contrary to what occurs with the yellowfin, there is some tendency for the catch rates to improve for these species in the area north of 5° N. latitude. Consequently it appears that the significance of this area as a fishing ground differs somewhat north and south of the line of 5° N. latitude. The reason for this is that south of 5° N. latitude most of the area is in the Equatorial Countercurrent, while north of 5° N. it is partly in the Countercurrent but mainly in the North Equatorial Current. Thus the two areas are in different current systems. From the foregoing facts it can be seen that the yellowfin are distributed in a very great density in the Equatorial Countercurrent and that their density of distribution falls off sharply in the North Equatorial Current.

If this region is divided into four parts, each comprising 10° of longitude, and if the fishing conditions within these divisions are compared as in the following table, it appears that there is also some difference in fishing conditions from east to west.

Table 32.--Fishing conditions in the region divided into areas of 10° of longitude (southern part of former South Seas Mandate)

Area	Number of trials	Number of hooks	Yellowfin		Bigeye		Spearfishes		Totals	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
130°-140° E.	212	88,189	2,413	2.74	81	0.09	311	0.35	2,805	3.18
140°-150° E.	214	207,735	6,907	3.32	1,098	0.53	2,088	1.00	10,093	4.85
150°-160° E.	262	348,951	12,450	3.57	2,090	0.60	2,342	0.67	16,882	4.84
160°-170° E.	8	2,814	100	3.55	16	0.57	11	0.39	127	4.51

Note: The albacore are included in the figures for yellowfin. Their respective numbers in the four areas from top to bottom are 4, 2, 136, and 0.

There are remarkably few data for the area from 160° to 170° E., so that it is impossible to compare it with the areas farther to the west. For the whole region the areas centered on 150° E. longitude show the highest catch rates. The majority of the catch is composed of yellowfin in all of the areas. Except for the extreme western portion, there is little discernible variation in the yellowfin catch rates. In the case of the bigeye tuna, it appears that there is a tendency for the catch rates to increase as one goes eastward. The catch rate for spearfishes is highest in the vicinity of the area of 140° to 150° E. longitude, that is west of the Caroline Islands. The albacore was scarce everywhere, but was markedly more abundant in the waters of the Caroline Islands than in the other areas.

Table 32 is based on data collected in the past and it completely ignores fluctuations from year to year in the fishing conditions, seasonal changes in catch rates, differences in the longitude of the points surveyed, and changes in the catch due to the construction of the fishing gear. Of these variables, the changes from year to year in the fishing conditions cannot be discussed with the data we have at our disposal. Nor do we have data which will enable us to make any judgments concerning the changes in fishing conditions brought about by differences in the construction of the gear. The fact that there are violent fluctuations in fishing conditions due to latitude was shown in table 31 and it is naturally to be imagined that there will be conspicuous changes in the fishing situation accompanying the change of seasons.

In order to see the effect of latitude on the differences shown in table 32, the following table presents the same east-west divisions further divided by the line of 5° N. latitude into northern and southern portions.

Table 33.--Fishing conditions in divisions of 10° of longitude on either side of the line of 5° N. latitude (southern part of former South Seas Mandate)

	0° - 5° N.				5° - 10° N.			
Area	Number of stations	Number of hooks	Number of fish	Catch rate	Number of stations	Number of hooks	Number of fish	Catch rate
130°-140° E.	49	39,514	1,602	4.05	163	48,675	1,203	2.47
140°-150° E.	97	121,074	7,022	5.80	117	86,661	3,071	3.54
150°-160° E.	180	255,169	13,080	5.12	82	93,782	3,802	4.05
160°-170° E.	4	2,094	115	5.49	4	720	12	1.67

Note: The catch rates are combined for tunas and spearfishes.

Leaving out of consideration the area east of 160° E. longitude because of the lack of data, the highest catch rates south of 5° N. latitude were in the area between 140° and 150° E. longitude. North of 5° N. latitude the highest catch rates were between 150° and 160° E. Catch rates were low between 130° and 140° E. both north and south of 5° N.

In order to see how the data in table 32 are affected by seasonal changes in the fishing conditions, the following table has been made using the same areas as table 32 and dividing the data according to whether they represent the season of southwesterly or northeasterly winds. The area between 160° and 170° E., for which little data is available, has been eliminated from this table.

Table 34.--Seasonal fishing conditions (southern part of former South Seas Mandate)

Area	Season of northeasterlies			Season of southwesterlies		
	Number of hooks	Number of fish	Catch rate	Number of hooks	Number of fish	Catch rate
130° - 140° E.	48,431	1,209	2.50	38,714	1,594	4.12
140° - 150° E.	202,725	10,014	4.95	5,010	79	1.58
150° - 160° E.	253,067	11,254	4.45	95,894	5,628	5.87
Total	504,223	22,477	4.46	139,618	7,301	5.24

Notes: 1. Southwesterly winds--April to September
Northeasterly winds--October to March

2. The catch rates are for tunas and spearfishes combined.

In general there are much fewer data for the season of southwesterly winds than for the northeasterlies, the difference being particularly notable in the area of 140° to 150° E. In this area fishing conditions during the southwesterlies are much inferior to those during the season of northeasterly winds, but in the other regions the contrary is true, with the southwesterlies affording the better fishing. On the whole, catch rates during the southwesterlies have values a little less than 1 percent greater than those for the season of northeast winds. Not only are data for the season of southwesterly winds in the area 140° to 150° E. very scarce, but what data there are are mainly from north of 5° N. latitude. These data were collected mainly by the research vessels of the South Seas Government General Fisheries Research Station and most of them are among the earliest such data collected in this region. Consequently the poor fishing due to the construction of the gear must be taken into consideration. If we can assume that this is the reason for the fishing in the area of 140° to 150° E. being so poor in comparison with the other areas, we can conclude that for the southern portion of the former South Seas Government General as a whole fishing is better during the southwest seasonal winds than during the northeasterlies. The question as to whether or not fishing conditions differ markedly in the area of 140° to 150° E. in comparison with other areas, or in other words whether the distribution and migration of the fishes within this area differ from those of other areas, will be difficult to decide unless future investigations provide more complete data.

If we again look at table 32, we see that the region between 130° and 140° E. longitude has a catch rate somewhat inferior to those of the other areas. However, area-wise the data for this section are mostly from north of 5° N. latitude and as regards the season, the proportion of data from the season of southwest winds is greater than in the case of other regions. It must further be noted that these data were mainly collected during the first part of the research program of the South Seas Government General. As will be explained later, fishing conditions in the East Philippine Sea, which is the westward continuation of this area, appear to be rather good. Taking all these facts into consideration, it can be thought that the area from the Equator to 10° N. in the Pacific, at least as far east as the area around 170° E. longitude, shows little variation in the value as fishing grounds of its various portions. Of course, taking into consideration changes in the ocean currents brought about by islands and other topographical features, it cannot be thought that this broad expanse of ocean is completely homogeneous as regards its value as a fishing ground. Furthermore, as regards the catch, the bigeye tuna show a tendency to increase toward the eastward, the spearfishes are most abundant in areas comparatively close to islands, and the abundance of the albacore seems to be somewhat localized. From these points of view, it cannot be affirmed that all parts of this region have the same characteristics as fishing grounds.

Table 34 shows in very broad terms the changes in the fishing situation accompanying the change of seasons by dividing the data between the two halves of the year. Needless to say, if the data were more adequate, it would be possible to get a more accurate grasp of the seasonal changes in the fishing conditions by a more detailed breakdown of seasons and areas. As there are very few areas for which data adequate to this end have been gathered, a thorough analysis is impossible. In connection with this point, some comments have been made under the heading "The Distribution of the Tunas as Shown by Catch Rates." For one part of this area the fishing situation by months is shown by the following table.

Table 35.--Fishing conditions by months (0° - 10° N 150° - 160° E)

Month	Number of stations	Number of hooks	Yellowfin		Bigeye		Spearfishes		Total	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	37	42,915	949	2.20	430	1.00	257	0.60	1,636	3.80
Feb.	25	30,902	304	0.98	120	0.68	176	0.57	690	1.61
Mar.	12	12,455	638	5.12	3	0.02	58	0.47	699	5.61
Apr.	14	18,110	576	3.18	67	0.37	116	0.64	759	4.19
May	16	26,028	1,521	5.84	65	0.25	149	0.57	1,735	6.67
June	--	--	--	--	--	--	--	--	--	--
July	19	33,405	1,721	5.15	171	0.51	191	0.57	2,083	6.23
Aug.	4	7,126	297	4.17	53	0.74	62	0.87	412	5.78
Sept.	6	10,225	559	5.47	152	1.49	73	0.71	784	7.67
Oct.	29	39,985	1,639	4.10	197	0.49	329	0.82	2,165	5.41
Nov.	51	63,202	2,509	3.97	348	0.55	493	0.78	3,350	5.30
Dec.	45	54,593	2,002	3.67	368	0.67	292	0.54	2,662	4.88

As records on the measurements of the individual fish in the catch are inadequate, it is not possible to make any comparisons of their areal or seasonal variations. To summarize very roughly, yellowfin of around 35 to 37 kilograms are generally most numerous, those from 20 to 30 kilograms and above 40 kilograms appearing to be scarce. A consideration of a certain amount of data makes it appear that there are seasonal changes in the size of the fish, but nothing is known for certain.

As was stated earlier, this region affords rather superior fishing grounds for tuna longline fishing. The most important species in the catch is the yellowfin tuna, followed by the spearfishes. Changes in fishing conditions accompanying changes in the seasons can be detected, but these changes are comparatively slight, showing that these are generally stabilized fishing grounds throughout the year.

7. Northern part of former South Seas Mandate (10° to 20° N., 130° to 170° E.)

This region is in the North Equatorial Current so there are no great changes in the currents throughout the year, the water always flowing from east to west. In the vicinity of

145° E. longitude, that is in the waters around the Mariana Islands, they take on a rather complicated aspect due to the influence of the topography, and northward and southward flowing currents appear. In the extreme western portion of this region, which is at the source of the Kuroshio, the current runs approximately northwest.

Water temperatures during the northeast monsoon are 26° C. to 27° C. at the surface. Temperatures at the 50-meter level do not differ greatly from the surface, and temperatures at the 100-meter level are approximately the same. During the southwest monsoon surface water temperatures are 28° C. to 29° C., temperatures at the 50-meter level do not differ greatly from those at the surface, and the temperature at the 100-meter level is about 27° C.

Water color throughout the year is I or II in the Forel scale and the transparency is high, being 35 to 40 meters in most cases.

During the height of the season of northeasterly winds, rather strong winds blow continuously in the western portion of this region, but it becomes somewhat calmer as one proceeds eastward. During the season of southwesterly winds the sea is generally extremely calm, but during the typhoon season storms often originate in this area. In this part of the ocean typhoons generally move westward or northwestward and many of them pass through the western portion of the region, so care on this point is necessary in operating there.

The significance and value of this area as a fishing ground is as yet almost completely unknown. Actual fishing operations have been carried on only around the Marianas and data from surveys and fishing experiments are confined almost entirely to that vicinity; consequently it is impossible to ascertain the fishing conditions throughout the region as a whole. A tabular summary of these data follows.

The general overall catch rate is 2.5, and the catch rates are conspicuously low in comparison with those between 0° and 10° N. latitude.

Table 36.--Fishing conditions in the northern part of the former South Seas Mandate (10° to 20° N., 130° to 170° E.)

Number of stations	Number of hooks	Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
98	65,811	382	0.58	152	0.23	113	0.17	1,004	1.52	1,651	2.51

The reason for the lowering of the catch rates in comparison with the southern portion of the former South Seas Mandate is the decline in the yellowfin catch. The catch rate for yellowfin is about one-sixth that of the former sea area, and even the rate for bigeye tuna is reduced by about half. On the other hand, the spearfish catch rate is approximately double and there is also a rather conspicuous increase in the albacore catch. Thus it should be noted that not only are the catch rates different as between the two areas, but the composition of the catch is also quite different. This is thought to mean that, as was previously noted for the Indian Ocean region, the distribution of these fishes is controlled more by differences in water systems than by temperature.

Since the data are almost entirely confined to the period December to February, it is unfortunately not possible to give any explanation of the seasonal changes in fishing conditions.

However, judging by the activities of commercial fishing vessels, fishing for striped marlin and black marlin is rather good in the northern Marianas from this period to around March or April. And it appears that quite a few medium-sized vessels have operated at this season in this area and somewhat to the eastward.

The Ogasawara Islands area to the north and the western Pacific north of 25° N. latitude have been gradually subjected to exploitation over a long period of years, but because of the sudden development of the fishing grounds of the southern part of the former South Seas Mandate, the fishermen skipped over the area presently under discussion and went directly to fish in the vicinity of the Equator. As a result the fishing grounds of this region have been left with hardly any attention paid to them and their significance and value as fishing grounds have been left almost completely unknown.

8. East Philippines Sea (0° to 30° N., 120° to 130° E.)

The area between 0° and 20° N. at 120° to 130° E., excluding those waters belonging to the Celebes Sea, Sulu Sea, and South China Sea, will be described as the East Philippines Sea.

That part of the area north of 5° N. latitude outside the coastal zone of the Philippine Islands is the so-called Philippine Trench, which is extremely deep and without any reefs or shoals on the bottom. South of 5° N. latitude there are scattered small islands and both the topography and the oceanographic conditions are complex.

During the season of southwest winds the part of this region between 10° and 15° N. latitude lies within the North Equatorial Current. Because of the impingement of this westward flowing current upon the Philippine Islands, the currents in waters adjacent to the Islands are quite complex. North of 15° N. latitude the currents flow generally north or northwest, forming the origin of the Kuroshio (Japan Current). South of 10° N. the currents turn south or southeastward, part of them entering the Celebes Sea and the rest flowing into the Equatorial Countercurrent together with the current which flows north to the Molucca Strait.

North of the central portion of the area the water temperatures are generally high, with temperatures from May to September of 28° C. to 29° C. at the surface, about 28° C. at 50 meters, and about 27° C. at 100 meters. In the southern portion the vertical distribution of water temperatures is remarkably complex, with occasional temperatures of about 20° C. reported for the 100-meter level. This condition is particularly marked in those areas adjacent to the Molucca Strait, and it appears that in many cases there are two to three marked thermoclines between the surface and about 200 meters. In most cases water color of I to II on Forel's scale and high transparencies of 30 to 40 meters have been recorded.

During the season in which northeasterly winds prevail the principal currents do not differ greatly from the pattern which they exhibit during the season of southwesterlies, but the current which flowed north through the Molucca Strait disappears and a current appears flowing in the opposite direction southward through that Strait. The boundary between the Equatorial Countercurrent and the North Equatorial Current is pushed somewhat southward from its position during the season of prevailing southwesterly winds.

Little is known of the distribution of water temperatures because of the paucity of the data, but compared to the season of southwesterlies temperatures in the northern part appear to be lowered by 2° - 3° C. at the surface, and 1° - 2° at 50 and 100 meters. In the southern portion the temperatures appear to be lowered by 1° - 2° C. at all levels. There is no great difference from the season of southwesterlies in water color and transparency.

During the season of southwesterly winds the surface is generally extremely calm. However, during the typhoon season the northern part of this sea area is frequently crossed by these storms and operating during this season requires considerable caution. During the northeasterlies operations are not infrequently hampered by high waves and seas.

It is only very recently that this area has attracted notice as a tuna longline fishing ground. In the early years of the Shōwa Era (the late 20's) the research vessel Shunkai Maru (180 tons) of the former Formosa Government General made some surveys in the northern part of the area, but the results were extremely poor, the area was ticketed as being almost valueless as a fishing ground, and it was thenceforth neglected. According to the commonly prevailing opinion at that time, an area like this one without reefs or shoals, and indeed one of the two deepest parts of the world's oceans, was adjudged to be unsuitable for the establishment of the tuna longline fishery.

The investigations of the Shunkai Maru were made in February. The investigations of the Shōnan Maru in this sea area were undertaken from June to September of 1937. As a result of the work of the Shōnan Maru it became known that this area was an extraordinarily good fishing ground, the attention of commercial operators was suddenly attracted, and a constant procession of vessels based at Takao began fishing there. In the beginning the principal object of the fishing in the northern portion was the black marlin and the main catch in the southern portion was yellowfin tuna. Beginning in the following year (1938), it gradually became known that the northern portion was an extremely fine black tuna ground and there was a sudden increase in the number of vessels fishing there for this species. The fishing season for black tuna, as was stated in the section on the South China Sea, is from the latter part of March to early June. The main fishing season for black marlin is from April to August, the fishing ground for this species being generally slightly farther off shore than that for the black tuna. Consequently, although the positions of the fishing grounds differed somewhat, the northern part of this sea area was judged to have ample value as a tuna longline fishing ground from April to around August to September. After September, that is with the start of the season of northeasterly winds, the fishing appears to deteriorate sharply, but the details of this are not clear because of the paucity of data.

Because of the distance, the southern part of this area, where yellowfin were the main catch, was not fished very much, only an occassional large vessel having operated there. It is certain that at some seasons it is an extremely good fishing ground, and it appears that in the most southerly portion seasonal changes in the fishing conditions are comparatively slight.

Most of the investigations in this area were made by the Shōnan Maru, Shunkai Maru, and Takao Maru. There are also some data from operations of the Kiyō Maru and the Zuihō Maru in the southern part of the area. The data from these various sources are summarized in the following table to indicate fishing conditions in this region.

Table 37.--Fishing conditions in the East Philippines Sea (0° to 20° N., 120° to 130° E.)

Stations	Hooks fished	Black tuna		Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
85	28,203	2	0.01	1,311	4.65	53	0.18	323	1.14	1,887	5.98

Catch rates are fairly high, nearly 6.0 . On the whole the data are scarce, and there are none at all for January, October, and December, so the seasonal changes in the fishing conditions are not well known, however, the data in the foregoing table can be divided between the northeast and southwest monsoons as follows.

Table 38.--Fishing conditions by seasons (East Philippines Sea)

Season	Number of stations and hooks	Black tuna		Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
NE monsoon	27 10,745	0	0.00	507	4.72	21	0.20	45	0.42	573	5.33
SW monsoon	58 17,458	2	0.01	804	4.61	32	0.18	278	1.60	1,114	6.38

Note: Northeasterlies--October to March; southwesterlies--April to September

It can be seen from the foregoing table that there is no great seasonal change in the fishing for yellowfin and bigeye tuna, but that the spearfishes increase markedly during the season of southwesterly winds. However, this table has lumped together the whole area of the East Philippines Sea, which extends 1,200 miles from north to south. There is therefore a need to examine variations in fishing conditions by area and by seasons within the area.

First of all, in order to examine the fishing conditions by area, we will divide the region by 5° of latitude and show the catch rates within each of these divisions in the following table.

Table 39.--Fishing conditions by sections (East Philippines Sea)

Sections	Number of stations and hooks	Black tuna		Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
0° - 5° N.	30 16,023	0	0.00	889	5.55	28	0.17	70	0.44	987	6.16
5° -10° N.	19 4,320	0	0.00	270	6.25	18	0.42	85	1.97	375	8.68
10° -15° N.	19 3,840	0	0.00	83	2.16	3	0.08	87	2.27	173	4.51
15° -20° N.	17 4,020	2	0.05	44	1.09	3	0.07	80	1.99	127	3.16

The foregoing table shows that in general the fishing is best between 5° and 10° N., followed by 0° to 5° N., with the catch rates falling off as one goes north from 10° N.

Black tuna were taken only between 15° and 20° N. In the case of the yellowfin, ther is a boundary in the vicinity of 10° N., with the catch rates dropping off sharply to the northwar South of 5° N. the catch rates are also somewhat lower than between 5° and 10° N. The spearfishes (chiefly black marlin) show their highest catch rates in the area between 10° and 15° N. Fishing is somewhat poorer between 5° N. and 10° N. and between 15° N. and 20° N., but the difference is slight. In the area from 0° to 5° N. the catch rates drop sharply as compared with the more northern areas, showing that there is a marked distributional boundary between 5° and 10° N. latitude. Bigeye tuna fishing is best between 5° and 10° N., with catches being made onl rarely farther to the north. In general the fishing within this area is controlled by the catch of yellowfin and spearfishes and, as the foregoing table shows, the yellowfin in the southern part an the spearfishes in the northern part are the main species controlling the fishing situation.

The situation is not thoroughly known because of the scarcity of data, but between 0° and 5° N. it appears that there are no marked fluctuations in the fishing throughout the year. It appears, however, that fishing is particularly active around March and from July to September North of 5° the spearfish catch increases from May to August.

The investigations of the Shōnan Maru cover almost the whole area north of 3° N. latitude from June to September. Based on these data, the catch rate curve from north to south for this sea area is shown in figure 9.

The variations in catch rate shown by the curve are rather large, but in general the yellowfin catch rates are clearly higher in the south and drop off sharply to the north. The spearfishes on the contrary are high in the north and low in the south. It is thought that the irregularity of these curves is due to the small number of fishing stations, and that if the number of stations were increased the curves would probably show more regular trends.

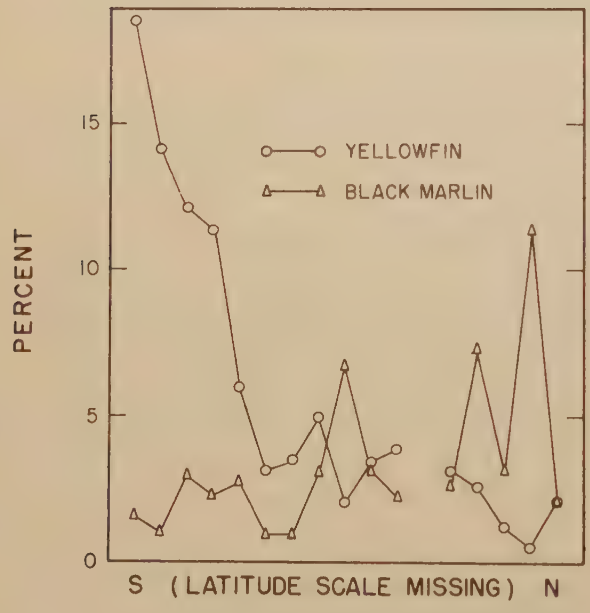

Figure 9.--Catch rates by latitudes (E. Philippines Sea)

The range within which the catch rate curves for the yellowfin and spearfishes intersect appears to be roughly from 10° to 15° N. Although differences can be detected in the numerical value of the catch rates, the situation outlined above appears to be exactly similar to that presented by the waters of the former South Sea Islands Mandate, which adjoins this area on the eastward.

If we attempt to compare these fishing conditions with oceanographic conditions, the area from 10° to 15° N. is where the North Equatorial Current impinges upon the Philippine Islands. Farther to the north the currents generally flow northward or northwestward and make up the origins of the Kuroshio. South of 10° N. the currents flow south or southeastward, corresponding in part to the area of origin of the Equatorial Countercurrent. The rest flow into the Molucca Strait area. Just as in the former South Sea Mandate farther to the east, yellowfin are abundant in the Equatorial Countercurrent and the spearfishes are abundant in the North Equatorial Current.

The only records concerning sizes of fish taken are the data from the Shōnan Maru's operations. Of 402 yellowfin taken in the course of the Shōnan Maru's work, the smallest was 2.8 kilograms, the largest 58 kilograms, and the average weight was 33 kilograms. Figure 10 shows the weight frequencies of these fish by 3-kilogram classes.

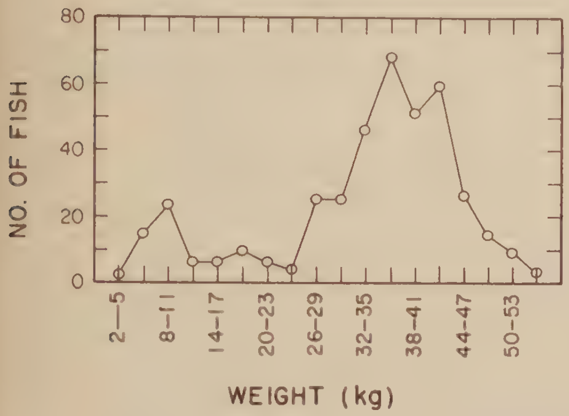

Figure 10.--Yellowfin weight frequencies (E. Philippines Sea)

As figure 10 shows, fish of about 35 - 38 kilograms were most numerous, with another peak at 41 - 44 kilograms. In the smaller sizes, there was a rather conspicuous peak at 8 - 11 kilograms. If we apply to these Professor Aikawa's age determination method, the peak of small fish represents fish in their fourth year, while the great majority are seventh- and eighth-year fish. The size distribution by latitude is not clear, but there seems to be some tendency for fish to be larger in the north and smaller in the south. The average weight of 33 kilograms is about the same as that for the former South Seas Mandate and is thought to show the identity of the populations. Nothing at all is known of seasonal changes in the size of the fish.

Weights of black marlin have been divided into 10-kilogram classes and their frequencies plotted as shown in figure 11. The data, like those for the yellowfin, are from the investigations of the Shōnan Maru and the number of fish is 165. As is clear from the figure, there is a very pronounced peak at 40 - 50 kilograms. The curve falls off steeply in the smaller sizes and also in the larger sizes. It is an interesting fact that a great majority of these fish were males, females being only 9 percent of the total and almost all of these were a very large size. Judging from a number of data, it appears that fishing from the central section on northward is subject to violent seasonal fluctuations, and after September the composition of the catch changes and fishing suddenly becomes poor. Seasonal fluctuations do not seem so violent in the southern part of the area, but on the whole it is the season of southwesterlies which shows the best fishing. This pattern is thought worthy of note as it appears also in the former South Seas Mandate and is particularly marked in the Celebes Sea.

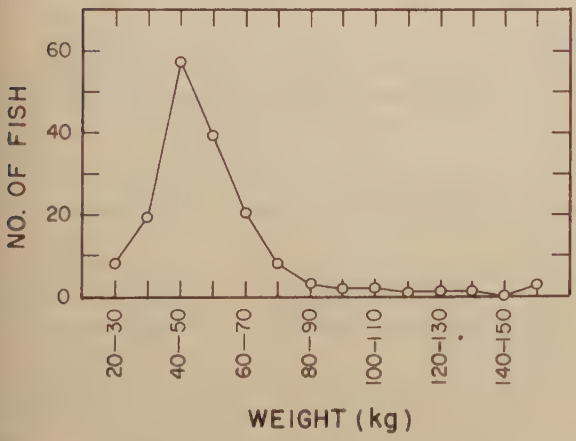

Figure 11.--Black marlin weight frequencies (E. Philippines Sea)

The foregoing facts indicate that, if area and season are taken into account, this region will also offer very superior fishing grounds.

9. East Formosa Sea and the waters of the Okinawan archipelago (20° to 30° N., 120° to 130° E.)

The waters of the East China Sea, east of the 100-fathom line and east of the Bashi Strait within the range of 20° to 30° N., 120° to 130° E. will be described as the East Formosa Sea and the waters of the Okinawan archipelago.

This area is almost all within the Japan current (Kuroshio) and, stated very broadly, the currents flow north or northeast throughout the year. However, in the western part of the area during the winter the effect of a cold current flowing south along the continent is fairly conspicuous. Furthermore, on the east side of the main Kuroshio current there is a great gyral flowing clockwise.

As this sea area stretches from the tropics through the subtropics to the temperate zone, there are rather conspicuous local and seasonal variations in water temperature and it is difficult to make a general discussion of the area as a whole.

Table 40 shows the changes in water temperature in the Bashi Strait at the extreme southern limit of this sea area.

Table 40.--Water temperatures in the vicinity of Bashi Strait (from Formosan Fishery Experiment Station Report for 1932)

Month	Depth (Meters)			
	0	25	50	100
February	23.9	23.9	23.9	23.5
May	28.1	27.0	25.1	21.6
August	28.7	28.6	27.9	23.9
December	24.9	24.9	24.8	23.7

The following table (table 41) shows the water temperatures for each month in the central part of the area at about the middle of the line between Suō (Formosa) and Yonakuni Island. The table is based on the regular sectional observations made by the Fisheries Experiment Station of the former Taiwan Government-General but do not all represent data from the same year, being averages of 13 years from 1919 to 1932.

According to this table the minimum surface water temperatures were 23° C. in March and the maximum 29.1° C. in August. Between 25 meters and 200 meters the minimum was in March and the maximum in September.

The data for the most northern part of this sea area are unequally distributed seasonally and therefore it is difficult to show changes throughout the year. Table 42 shows changes in the water temperatures based on data from sectional observations carried out by the Kagoshima Prefecture Fisheries Experiment Station. The values shown in the table are those from a station 50 miles off Yakushima on a line connecting Yakushima and Ōshima. The data do not all represent the same year but are a collection of data covering several years.

Comparing these three tables, it appears that there is little difference between tables 40 and 41. Even in table 42 little difference can be seen in the summer, but in the winter the temperatures are 2° - 3° C. lower.

Table 41.--Water temperatures in the vicinity of 25° N.
(the center of the line from Suō to Yonakuni)

Depth	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	23.4	23.8	23.0	24.7	26.7	27.8	28.3	29.1	28.9	27.4	26.0	25.3
25	23.6	23.7	22.9	24.7	26.2	27.6	27.9	27.8	28.2	27.3	26.0	25.4
50	23.5	23.4	22.9	24.6	25.8	25.9	26.2	26.8	26.9	27.1	25.9	25.3
100	23.2	22.4	21.3	23.2	22.1	23.7	24.1	22.7	24.3	22.8	25.0	23.4
200	19.2	18.6	17.7	19.0	20.4	18.9	19.9	18.2	17.1	16.7	18.8	19.4
400	13.2	13.4	11.7	12.8	14.2	13.1	14.0	12.6	13.1	11.5	12.9	12.9

Note: From the report of the Formosa Fisheries Experiment Station for 1932.

Water temperature is generally I to II on Forel's scale and transparency values are generally high. However, close to the 100-fathom line of the continent these values are somewhat lower.

During the winter there are strong north or northeast winds in the southern part of this area and westerly winds in the northern part, and the sea is generally rough. During the summer it is generally calm, but during the typhoon season storms frequently cross this area so caution is necessary.

Table 42.--Water temperatures south of Yakushima

Depth	Month					
	Feb.	Mar.	May	July	Aug.	Nov.
0	21.2	20.8	25.1	25.9	29.5	24.7
25	21.3	20.9	24.8	25.8	28.9	24.7
50	21.3	20.6	24.7	25.4	28.6	24.8
100	21.2	20.5	23.8	18.8	28.4	23.8
150	20.6	19.2	21.8	17.4	25.9	22.0

This sea area has been exploited as a fishing ground for many years. The following is a general description of fishing conditions there from south to north.

The East Formosa Sea region was first exploited as a tuna fishing ground in the Taishō Era (1912-1925). In the beginning there was a skipjack fishery based at Keelung, and then attention was drawn to the fact that spearfishes were extraordinarily abundant in this area. The former Formosa Government-General established fishing ports at Keelung, Suō, Shinkō, and Karenko and made them bases for a fishery. At the same time fishermen were invited to emigrate from Ōita, Ehime, Kōchi, Wakayama, and Chiba prefectures and a positive program of fishery development was carried on. These emigrants mainly engaged in the harpoon fishery.

The spearfishes are very abundant in the waters off Formosa and the catch of these fishes rivals and at times surpasses that of the tunas, of which the yellowfin is the principal species. The Formosan spearfish catch is even greater than that of Japan proper.

The fishing season of the harpoon fishery in the East Formosa Sea is limited to the period of the prevailing northeasterlies from October to April. This is just the opposite of the situation in the waters of Japan proper, where this fishery is limited almost entirely to the summer season. In general the fishing is most active in the southern part of this sea area at the beginning of the fishing season and with the passage of time the center of the fishing grounds gradually shifts to the northward. In the middle of the season the grounds are centered off Suō, and at the end of the season the Hōkasho area becomes the center. There are also seasonal differences in the composition of the catch, with white marlin abundant at the beginning of the season, striped marlin increasing toward the middle of the season, and black marlin gradually increasing toward the end. However, in the overall picture white marlin are the most abundant. Table 43 shows the changes in the fishing situation from month to month.

Table 43.--Catch of the harpoon fishery, Suō, 1934 and 1943 (numbers of fish)

Month	Species			
	White marlin	Black marlin	Striped marlin	Sailfish
January	1,401	80	1,448	180
	934	12	82	7
February	902	258	913	181
	1,007	42	77	23
March	1,013	250	502	115
	1,114	45	92	51
April	462	169	97	97
	345	15	351	381
May	34	5	5	179
	97	21	48	434
June	6	3	6	256
	10	19	8	409
July	4	9	4	308
	1	4	2	73
August	11	30	1	253
	0	0	0	3
September	8	9	5	58
	0	0	0	0
October	648	49	632	786
	23	2	2	21
November	1,990	86	814	236
	433	3	31	119
December	1,264	116	1,030	61
	484	17	49	72
Total	7,748	1,064	5,497	2,710
	4,448	161	742	1,593

Note: The upper figures are for 1934, the lower figures for 1943. The marked decline in 1943 is due to the war.

At first the harpoon fishery was operated almost entirely by Japanese emigrants. There was, in addition, a flourishing longline fishery in this sea area carried on for the most part by Formosans. The catch of this longline fishery was mainly sharks, such as the hammerhead, yashibuka, dotabuka, and threshers, and few tunas or spearfishes were taken. The fishing ground and fishing season coincided completely with those of the harpoon fishery.

At about the time the harpoon fishery comes to an end, black tuna migrate into the southern part of this sea area, and by the middle of June they are taken all over the area. In the beginning of the season the fishing is comparatively concentrated, but toward the end of the season it gradually becomes more dispersed and the fishing grounds shift gradually from south to north. However, as there is sporadic fishing of black tuna at almost the same season in the waters contiguous to this area on the south and north, if the schools do move from south to north, it is in a remarkably dispersed state.

It is thought that from about the time the black tuna season ends, dense schools of black marlin migrate into the area, but we do not as yet have any concrete data concerning this fact. The basis for this supposition is, as was stated in the section on the East Philippines Sea, that between May and September dense schools of this species are seen in the North Equatorial Current and the region of the origins of the Kuroshio, and there are two or three records showing that quite a few black marlin are taken about the same time in the Yonakuni Island area. It is considered that their fishing grounds are probably farther off shore than the harpooning grounds, and as there have actually been hardly any fishing vessels operating there, nor any experimental or exploratory fishing, there are no data at all to offer as evidence.

As the foregoing shows, this area has hardly been considered as a fishing ground during most of the season of southwesterly winds. The fishing ground during the northeast monsoon, both in the case of the harpoon fishery and the longline fishery, is extremely coastal in character, being limited to within 30 miles of the shore. The situation farther off shore was investigated by the Shōnan Maru, Shichisei Maru (fisheries research vessel of the former Taihoku Province), and the Takao Maru, which caught considerable amounts of tunas, spearfishes, and sharks, however, it can by no means be thought to be a superior fishing ground.

The waters of the Okinawan archipelago are noted as a fishing ground for sedentary skipjack rather than as a tuna ground. Nevertheless, tunas and spearfishes are taken throughout the region and certain localities are known to be outstanding longlining grounds. There are excellent grounds between Uotsuri Shima and the Miyako Archipelago and south of the main island of Okinawa, and at the extreme northern end of the area is the famous black tuna ground around Tanegashima.

Throughout the area as a whole the spearfishes are most abundant, followed by yellowfin, bigeye, and black tuna, with albacore extremely scarce. The spearfishes are abundant throughout the year, but particularly from April to August and in general east of 125° E. longitude. The most abundant species is the white marlin, followed by the striped marlin and the black marlin. The seasonal changes in abundance of different species are the same as for the East Formosa Sea. The catch of sailfish also appears to increase during the summer. After August the fishing shifts to the vicinity of the 100-fathom line in the East China Sea, and the fishing grounds of this region, although they differ from season to season, extend through the waters west of Kyūshū on the north to the Tsushima Strait area.

Yellowfin are fairly abundant in April - May and November - December, and a tendency can be detected for catch rates to increase gradually to the eastward. Bigeye tuna are rather abundant from November to January but appear to be hardly taken at all at other seasons. There are two fishing seasons for black tuna; one is around December and January, with the fishing grounds in the extreme northern part of the region. However, fishing is not very good at this time and the catches are made at some distance from the center of the main fishing grounds. The other season is around April to June, with the grounds on the east side of the archipelago. The fishing is sporadic and there are no concentrated catches. Some albacore are taken from January to March, but they are not very abundant. Table 44 shows the fishing situation in this sea area on the basis of past surveys.

The overall catch rate is slightly less than 2.0, much lower than those of the various sea areas described earlier. Comparing those parts of the area north and south of 25° N. latitude, as the table shows, the catch rates are higher in the north for all fish except the yellowfin, and the overall average catch rate is higher in the north. It will be noted that the catch rates for black tuna and albacore are much greater in the northern part.

Table 44.--Fishing situation in the East Formosa Sea and the waters of the Okinawan archipelago (20° to 30° N., 120° to 130° E.)

Area	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
20°-25°N.	8	0.02	162	0.43	69	0.18	1	0.00	364	0.98	604	1.62
25°-30°N.	131	0.22	161	0.27	139	0.23	109	0.18	722	1.19	1,262	2.08
Total	139	0.14	323	0.33	208	0.21	110	0.11	1,086	1.11	1,866	1.90

Note: Number of stations fished 20° N. to 25° N. = 197
" " " " 25° N. to 30° N. = 227

Number of hooks fished 20° N. to 25° N. = 37,290
" " " " 25° N. to 30° N. = 60,694

Because of the extreme paucity of the data, a thorough comparison is impossible, however, tables 45 and 46 show the seasonal variations in fishing conditions.

Black tuna are taken in May. Yellowfin are most abundant from October to December. The spearfishes have a catch rate of about 1.0 throughout the year and show a potentiality for a higher catch rate in June.

Black tuna catches are centered around May, with fair numbers taken in April and June, and sporadic catches from October through November. Yellowfin are taken in all months except February, August, and September, and the catch rates increase from April through July and in December and January. Bigeye tuna show about the same variations as yellowfin, but the peak of their catch rate which appears in the summer is markedly lower than that for the yellowfin. Albacore are taken only in the winter, none at all having been caught in the summer. The spearfishes show rather high catch rates from June through September, but the fishing for them becomes remarkably poor in March and April. There are very few data for the southern part of the area, as shown in table 45, so it is not possible to make a thorough comparison with table 46, however, it can probably be recognized that both the northern and southern halves of the region show the same trends of rise and decline. In general, only a few of the summer months can be considered superior fishing in this sea area, the winter fishing season being shorter and having lower catch rates than the summer.

In tables 44 to 45 the difference in location from east to west is not taken into consideration at all. In the following table the fishing situation is presented with this area divided up by 2° of longitude without reference to latitude.

Black tuna are taken only between 124° and 126° E. longitude, that is in the waters around the Sakishima Islands. Yellowfin are caught at almost the same rate throughout, except for the most easterly area. There is some doubt however, as to whether this trend really exists because there are few data for the region between 128° and 130° E. longitude. The bigeye tuna appear comparatively close to the coast, and the spearfishes show a tendency for catch rates to increase to the eastward.

Table 45.--Fishing conditions by months (East Formosa Sea and southern waters of the Okinawan archipelago, 20° to 25° N., 120 to 130° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	3,556	0	0	7	0.20	16	0.45	0	0	49	1.38	62	2.03
Feb.	6,794	0	0	15	0.22	15	0.22	0	0	69	1.02	99	1.46
Mar.	384	0	0	0	0	0	0	0	0	1	0.26	1	0.26
Apr.	--	--	--	--	--	--	--	--	--	--	--	--	--
May	1,557	8	0.51	2	0.12	3	0.18	0	0	11	0.71	24	1.52
June	873	0	0	2	0.23	0	0	0	0	36	4.35	38	4.58
July	675	0	0	0	0	0	0	0	0	7	1.04	7	1.04
Aug.	--	--	--	--	--	--	--	--	--	--	--	--	--
Sept.	--	--	--	—	--	--	--	--	--	--	--	--	--
Oct.	2,412	0	0	13	0.54	1	0.04	0	0	17	0.70	31	1.28
Nov.	5,824	0	0	15	0.26	0	0	0	0	48	0.82	63	1.08
Dec.	16,584	0	0	122	0.74	36	0.22	0	0	133	0.80	296	1.76

Table 46.--Fishing conditions by months (northern part of the Formosa-Okinawa area, 25° to 30° N., 120° to 130° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	8,854	0	0	40	0.45	74	0.84	93	1.05	44	0.50	251	2.84
Feb.	1,064	0	0	0	0	0	0	0	0	17	1.60	17	1.60
Mar.	6,436	0	0	4	0.06	4	0.06	7	0.16	4	0.06	19	0.34
Apr.	1,026	4	0.38	14	1.36	0	0	0	0	3	0.29	21	2.03
May	7,326	98	1.34	46	0.63	5	0.07	0	0	139	1.90	288	3.94
June	5,402	27	0.50	15	0.28	1	0.02	0	0	117	2.16	160	2.96
July	684	0	0	8	1.17	0	0	0	0	23	3.36	31	4.53
Aug.	2,244	0	0	0	0	0	0	0	0	82	3.70	82	3.70
Sept.	4,348	0	0	0	0	0	0	0	0	98	2.25	98	2.25
Oct.	7,174	2	0.03	5	0.07	2	0.03	0	0	81	1.13	90	1.26
Nov.	8,939	2	0.02	14	0.15	21	0.23	4	0.04	73	0.91	114	1.35
Dec.	3,474	0	0	15	0.43	26	0.75	4	0.12	29	0.84	74	2.14

Table 47.--Fishing conditions by longitude (East Formosa Sea and southern part of Okinawan archipelago 20° to 25° N., 120° to 130° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
120°-122° E.	1,736	0	0	9	0.52	0	0	10	0.58	19	1.10
122°-124° E.	23,395	0	0	98	0.42	42	0.18	179	0.77	319	1.37
124°-126° E.	10,595	8	0.08	48	0.45	27	0.26	139	1.31	222	2.10
126°-128° E.	1,114	0	0	6	0.54	0	0	26	2.33	32	2.87
128°-130° E.	450	0	0	1	0.22	0	0	10	2.22	11	2.44

Table 48.--Fishing conditions by longitude (East Formosa Sea and northern part of Okinawan archipelago, 25° to 30° N., 120° to 130° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
122°-124°E.	6,201	0	0	0	0	0	0	0	0	98	1.58	68	1.58
124°-126°E.	10,926	37	0.34	16	0.15	11	0.10	12	0.11	224	2.05	300	2.75
126°-128°E.	26,753	88	0.33	82	0.31	19	0.07	59	0.22	315	1.18	563	2.11
128°-130°E.	16,814	6	0.03	63	0.37	109	0.65	38	0.22	95	0.56	311	1.83

Note: West of 122° E. is the continental shelf, where this fishery is not carried on.

As the table shows, there are no tunas taken at all west of 124° E., only spearfishes being taken there. Black tuna are most numerous from 124° to 128° E. and become scarcer farther out to sea. Yellowfin show a tendency to increase to the eastward, and this trend can also be detected in the bigeye and albacore. The spearfishes are fairly abundant over the whole area, but show their highest catch rates in the central part.

The overall catch rate for this area is slightly less than 2.0, remarkably lower than the 5.90 of the East Philippine Sea and somewhat lower than the 2.51 of the northern part of the former Mandate, that is, 10° to 20° N., east of 130° E. Consequently this sea area is thought to have less value as a fishing ground than the area to the south of it. However, if the distance between bases and fishing grounds is taken into account, the value and significance of an area as a fishing ground cannot be decided solely in terms of the catch rate. On this account the value of the fishing grounds of this sea area will naturally be enhanced. Particularly as it is clear that at some seasons there are rather high catch rates, it is considered that fishing in this area will be quite profitable if no error is made in selecting the fishing ground and the fishing season.

10. Western Pacific subtropical sea area (20° to 30° N., 130° to 180° E.)

The area between 130° and 180° E. longitude and 20° to 30° N. latitude will be discussed as the western Pacific subtropical sea area. This is an extremely broad area, but oceanographic conditions are comparatively uniform throughout the whole region. However, in the vicinity of the Volcano Islands, the Ogasawara Islands, and the northern Marianas where the topography is complex, the oceanographic conditions are also somewhat complicated. The same is true of the area around the Okinawan archipelago in the extreme west.

The area is generally under the influence of the Kuroshio Countercurrent. From the Volcano Islands to the Ogasawara Islands there is a rather strong northward flowing current along the east side of the island chains. This is called the Ogasawara Current and is particularly strong during the summer.

The southern part of the area is within the North Equatorial Current and here the current flows from east to west throughout the year. Along the northern edge of the North Equatorial Current there are here and there branch currents flowing northwest. These are particularly conspicuous in the summer at which season they generally change the direction of their flow from northwest to northward. In the northern part of the area there are branch currents of the Japan Current and the North Pacific Current flowing south or southeastward, and it is said that here and there great clockwise gyrals are formed. The North Pacific Current is the name given to that part of the Kuroshio (Japan Current) which leaves Japanese waters and flows eastward, and the southward or southeastward branches mentioned above are called the Kuroshio Countercurrent. Where the North Equatorial Current and the Kuroshio Countercurrent come into contact is the so-called subtropical convergence. This subtropical line of convergence runs approximately east and west along the parallels of latitude. Accordingly, completely different water systems are found to the north and south of the convergence.

The position of the subtropical convergence differs greatly with the seasons. When the water temperatures are at their lowest around February and March, it runs east and west along a line at about 23° to 24° N., and when water temperatures are at their highest in September, it moves far to the north and runs east and west in the vicinity of 30° N.

The distribution of water temperatures is controlled by the above mentioned currents and the isotherms run roughly parallel to the parallels of latitude. Around February and March the 22° C. isotherm runs east and west along the line of 24° to 25° N. or roughly at the center of this sea area. In the summer the 28° C. isotherm appears at approximately the same position. Table 49, based on data from the waters adjacent to the Ogasawara Islands, shows by months the water temperature, specific gravity, and transparency in the vicinity of 25° N. latitude.

As the table shows, the water temperatures are at their lowest in March with values of about 19.5° C. from the surface to the 30-meter level. The maximum is in July with 27.9° C. at the surface. Table 49 represents records for one year from April 1931 to March 1932. From the 10-year averages given in the same report, it appears that the minimum temperature at the surface is 20.6° C. in February and the maximum is 27° C. in August.

In the winter strong northwesterly or westerly winds blow continuously, being particularly violent in the northern part of the area. In the summer the sea is generally extremely calm except when typhoons are being generated.

This sea area was opened as a fishing ground around the middle of the Taishō Era (around 1920) and all parts of it have been fished by large numbers of fishing boats. The fishing grounds were expanded to the eastward and southward as the size of the fishing boats was increased, and the albacore grounds in the eastern part of the area were developed very rapidly after the early years of the Shōwa Era (from 1926 on). Thereafter, from 1936 on, the yellowfin grounds of the equatorial region attracted the attention of the fishing industry, and the fishing boats jumped directly to that area, so that except for particular localities the significance and value of the fishing grounds of the southern part of this sea area are in many ways not clearly known.

Table 49.--Oceanographic conditions by months in the waters of the Ogasawara Islands

Month	Water temperature (°C.)			Specific gravity			Transparency (meters)	Air temp. (°C.)
	0 m	15 m	30 m	0 m	15 m	30 m		
1931 Apr.	20.7	20.5	20.3	25.50	25.58	25.60	20.6	21.0
May	21.9	21.6	21.6	25.87	25.89	25.96	22.6	23.4
June	24.2	23.0	22.8	25.20	25.22	25.27	21.6	25.9
July	27.9	27.4	26.9	25.61	25.62	25.61	20.2	29.8
Aug.	27.2	26.5	26.1	25.66	25.63	25.74	21.8	29.3
Sept.	27.1	26.5	25.5	25.80	25.76	25.80	26.3	29.8
Oct.	27.8	26.7	25.5	25.99	25.96	26.01	27.8	29.3
Nov.	25.8	25.1	24.1	26.18	26.19	25.89	24.0	27.4
Dec.	22.5	22.2	22.0	25.71	25.68	25.72	24.9	22.7
1932 Jan.	21.2	20.9	20.7	25.72	25.67	25.72	31.5	19.7
Feb.	20.3	20.2	19.9	26.01	25.99	25.63	25.2	18.0
Mar.	19.7	19.5	19.4	25.79	26.13	26.10	21.2	20.0

Note: From report of Ogasawara Fisheries Enterprises for 1931.

Considering this sea area as a whole as a tuna longlining ground, it is by no means uniform everywhere, but presents fishing grounds of different character in different localities such as the black tuna grounds south of Tanegashima, the yellowfin and spearfish grounds from Daitō Island to the Kōhō Shoal area, the albacore grounds of the Kinanshō area, the spearfish grounds in the coastal waters of the Ogasawara and Volcano islands, and the bigeye tuna and albacore grounds to the eastward. And as will be explained, fishing conditions are quite different to the north and south of a boundary in the vicinity of 24° to 25° N.

In the following discussion this sea area is divided into three regions from west to east and the characteristics of the fishing grounds in each of these regions are discussed separately.

(a) 130° to 140° E. longitude

The northwestern part of this sea area forms part of the so-called Tanegashima black tuna grounds. In recent years the black tuna have completely disappeared and only a certain number of bigeye are taken during the season. In the vicinity of 30° N., 137° E. there are the famous Kinanshō fishing grounds and here albacore are abundant in the winter. The vicinity of 24° to 26° N., 131° E. is famous as the so-called Daitō Island fishing ground, and the principal catch here is spearfishes and yellowfin. The Kōhō Shoal, discovered by and named for the Kōchi Prefecture fishery research vessel Kōhō Maru, is at 26° N., 136° E. At certain seasons yellowfin and spearfishes are abundant on this ground.

Table 50 summarizes data from surveys carried out in this sea area.

The overall average catch rate is 2.4, with a slightly higher rate of 2.84 to the south of 25° N. as compared with 2.24 to the north. The composition of the catch is quite different north and south of 25° N. In the south yellowfin make up more than half the catch while albacore are most abundant in the north. Black tuna are taken only in the north, there being no record of their capture in the southern part of the area, and their average catch rate throughout the year is 0.22. There is almost no difference between the catch rates for the spearfishes, but the catch rate for bigeye tuna is somewhat higher in the south.

Table 50.--Fishing conditions at 20° to 30° N., 130° to 140° E.

Area	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
20°-25° N.	48,858	0	0	806	165	265	0.54	48	0.10	267	0.55	1,386	2.84
25°-30° N.	124,116	275	0.22	455	0.37	366	0.30	975	0.79	696	0.56	2,767	2.24
Total	172,974	275	0.16	1,261	0.73	631	0.37	1,023	0.59	963	9.63	4,153	2.40

Note: The number of fishing stations is 105 from 20° to 25° N. and 590 from 25° to 30° N.

Seasonal changes in the fishing conditions are not well known because of the scarcity of data, but table 51 shows what is known.

Table 51.--Fishing situation by months (20° to 25° N., 130° to 140° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	4,579	0	0	52	1.13	8	0.17	4	0.09	17	0.36	81	1.75
Feb.	2,100	0	0	12	0.57	11	0.52	3	0.14	10	0.48	36	1.71
July	1,974	0	0	48	2.43	0	0	0	0	22	1.11	70	3.54
Oct.	576	0	0	0	0	1	0.17	0	0	0	0	1	0.17
Nov.	17,751	0	0	273	1.54	105	0.59	6	0.03	97	0.55	481	2.71
Dec.	21,588	0	0	406	1.90	128	0.60	33	0.15	88	0.41	655	3.06

Note: There are no data at all for months other than those shown on the table.

As the data are almost entirely limited to the winter, it is not possible to give any details on the fishing conditions in the summer, however, the data for July indicate that yellowfin are fairly abundant at that time and the spearfish catch rate is also high. There appear to have been almost no catches of other species. Yellowfin are shown to be fairly abundant for a 2- to 3-month period centered around December. Bigeye tuna are fairly numerous in November and December and increase also in February. Albacore are extremely scarce, but some are taken in the winter. Spearfishes are most abundant in July and are scarce in the winter.

This pattern appears to coincide in general with the trend of fluctuations in abundance in the adjacent East Formosa Sea area on the west, although there are some differences in the values (see table 45).

Table 52 shows the fishing situation by months north of 25° N.

Table 52.--Fishing conditions by months (25° to 30° N., 130° to 140° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	31,864	168	0.53	20	0.07	32	0.10	6	0.02	194	1.61	420	1.33
Feb.	13,491	63	0.47	11	0.08	53	0.40	43	0.32	96	0.71	266	1.98
Mar.	40,809	266	0.65	12	0.06	52	0.12	347	0.71	107	0.25	784	1.79
Apr.	3,612	4	0.11	0	0	4	0.11	1	0.03	20	0.54	29	0.79
May	1,684	5	0.30	2	0.12	1	0.06	0	0	44	2.70	52	3.16
June	4,024	3	0.07	1	0.02	0	0	0	0	100	2.48	104	2.57
July	196	0	0	0	0	0	0	0	0	3	1.53	3	1.53
Oct.	12,664	1	0.01	136	1.07	84	0.68	3	0.02	29	0.23	253	2.01
Nov.	20,485	0	0	101	0.49	134	0.65	17	0.08	40	0.19	292	1.41
Dec.	22,235	12	0.05	50	0.22	159	0.71	16	0.07	64	0.27	301	1.32

Note: There are no data for August and September.

Black tuna are most abundant from January to March, and they appear to increase again somewhat around May. Fluctuations in fishing conditions throughout the year are not clear because data are lacking for August and September, but within the period covered by the table some black tuna were taken in all months except July and October. In general yellowfin are extremely scarce, with a catch rate of slightly more than 1.0 in October declining gradually from November on. Bigeye tuna are most abundant from October through December and show their highest catch rate of the year in the latter month. Albacore are taken only during the winter and the catch rate is at its peak in March. Spearfishes are more numerous in the summer, being most abundant around May and June. In the winter their catch rate increases somewhat in January and February. In general catch rates are higher in the summer, the main reason being that the catch of spearfishes increases.

Comparing these conditions with the Okinawa area adjoining on the west, a particularly marked difference can be detected in the black tuna fishing. That is, in the Okinawan region black tuna are taken only from April to June, with their highest catch rates in May. In this sea area there are, as explained above, two seasons for this species, the main one being from January through March, with another separate peak in the catch rate in May. It is naturally hypothesized that the schools which appear in May are the same as those which appear in the Okinawan area, but the relationships of the schools which come from January to March are not clear. It is thought that almost no difference can be seen in the two areas as regards fluctuations in fishing conditions for tuna species other than the black tuna. It appears, however, that in some cases there may be, depending on the species, more or less of a lag in the time of the peak season.

Regarding the spearfishes, which are the most important catch in both these of sea areas, it looks as if the seasonal changes in fishing conditions are of completely identical pattern, with the catch rate at its highest from May to August. Unlike the tunas, the spearfish catch rates are always fairly high throughout the year and there is no season at which none are taken.

In order to compare fishing conditions from east to west, the area has been divided into five parts by 2° of longitude and table 53 gives ithe fishing situation for each of these sections.

Table 53.--Fishing conditions by sections (20° to 25° N., 130° to 140° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
130°-132°E.	--	--	--	--	--	--	--	--	--	--	--	--	--
132°-134°E.	15,420	0	0	145	0.94	84	0.54	5	0.03	51	0.32	285	1.83
134°-136°E.	9,564	0	0	276	2.89	76	0.80	9	0.10	56	0.58	417	4.37
136°-138°E.	22,426	0	0	380	1.70	104	0.46	34	0.15	137	0.61	655	2.92
138°-140°E.	1,412	0	0	5	0.35	1	0.07	0	0	23	1.63	29	2.05

The yellowfin are most abundant around 134° to 136° E., that is, in the vicinity of Kōhō Shoal, as are bigeye too. Few albacore are taken, but they appear to show some tendency to increase to the eastward. The spearfishes tend to be most numerous in the extreme eastern portion, that is west of the Volcano Islands, but it is difficult to state this definitely because of the paucity of the data.

Table 54 shows fishing conditions in the same sections north of 25° N.

Black tuna clearly decrease sharply from west to east, and yellowfin are most abundant between 134° and 136° E. The bigeye have a distribution resembling that of the yellowfin, and albacore catch rates increase as one goes eastward, the so-called Kinanshō fishing grounds being thus shown to be a superior albacore ground.

It is difficult to detect any clear trend for the spearfishes, but the catch rates are somewhat better in the extreme western portion, and between 136° and 138° E.

Table 54.--Fishing conditions by sections (25° to 30° N., 130° to 140° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
130°-132°E.	72,044	249	0.34	133	0.18	290	0.41	53	0.07	481	0.67	1,206	1.67
132°-134°E.	10,077	21	0.21	33	0.33	25	0.25	23	0.23	43	0.43	145	1.45
134°-136°E.	24,810	2	0.01	168	0.70	153	0.62	8	0.03	64	0.26	395	1.62
136°-138°E.	9,785	3	0.03	5	0.05	28	0.28	266	2.74	82	0.83	384	3.95
138°-140°E.	7,400	0	0	0	0	29	0.39	388	5.24	26	0.35	443	5.98

Comparing tables 53 and 54, fluctuations in yellowfin fishing conditions show approximately the same trend, as do those for the bigeye. The trend for the albacore also appears to agree, but a very great difference in catch rates can be detected. The spearfishes appear to differ somewhat, but it is difficult to detect any clear-cut tendency.

Ample note should be taken of this complete change in the composition of the catch north and south of 25° N. latitude.

(b) Ogasawara, Volcano, and Mariana islands (20° to 30° N., 140° to 150° E.)

The northern part of this sea area has been exploited as a fishing ground since very old times. The southern portion, too, has quite a history as a fishing ground and has been fished by many vessels. The principal components of the catch are albacore and spearfishes in the north and yellowfin and spearfishes in the south. Among the spearfishes of the north quite a few broadbill are included, these being taken together with albacore during the winter. The spearfishes in the southern part of the area are mainly striped marlin and black marlin, and their season is in the summer.

Table 55 summarizes the data from investigations carried on in this area.

Table 55.--Fishing conditions in the waters of the Ogasawara, Volcano, and Mariana islands (140° to 150° E.)

Area	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
20°-25°N.	135,691	0	0	395	0.29	254	0.18	145	0.11	1,448	1.07	2,242	1.65
25°-30°N.	132,214	10	0.01	180	0.14	238	0.18	4,215	3.18	1,493	1.13	6,136	4.63
Total	267,905	10	0	575	0.21	492	0.18	4,360	1.63	2,941	1.10	8,378	3.12

Throughout this sea area as a whole the catch rate is slightly more than 3.0, a bit higher than that of the area of 130° to 140° E. adjoining on the west. The principal catch is albacore and spearfishes. There are vestigial catches of black tuna in the northern part, but they are not taken at all in the south. Yellowfin are abundant in the southern part, where their catch rate is twice that of the northern section. No local differences in the fishing situation for bigeye tuna north and south of 25° N. can be detected. Albacore are extremely scarce in the south but have a fairly high catch rate in the north. Spearfishes are somewhat more abundant in the north, but the difference is slight. Many sharks, of which the most important is the great blue shark, are taken in this area, their numbers rivaling the combined total for tunas and spearfishes and in many cases surpassing them.

If tables 55 and 50 are compared, rather conspicuous differences in the values of the catch rates can be seen, but the trends of changes in fishing conditions north and south of 25° N. are shown to be in good agreement. This fact is believed to show the similarity of the pattern of distribution of these fishes in both areas.

Tables 56 and 57 present the fishing conditions by months in order to show seasonal changes. The data are unfortunately not evenly distributed, but there are data for almost the whole year so that it is possible to ascertain the fluctuations in fishing conditions during the year.

Table 56.--Fishing conditions by months (20° to 25° N., 140° to 150° E.)

Month	Number of hooks	Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	3,188	19	0.59	22	0.69	7	0.22	95	2.96	144	4.49
Feb.	12,742	17	0.13	28	0.22	8	0.02	89	0.70	151	1.19
Mar.	37,196	83	0.22	84	0.22	31	0.08	385	1.04	583	1.57
Apr.	14,651	35	0.24	10	0.07	5	0.03	97	0.69	147	1.00
May	5,688	17	0.21	0	0	1	0.02	60	1.05	78	1.37
June	5,718	24	0.42	0	0	12	0.21	69	1.20	105	1.83
July	16,668	84	0.50	25	0.15	7	0.04	202	1.21	318	1.91
Aug.	400	2	0.50	2	0.50	0	0	6	1.50	10	2.50
Sept.	18,126	64	0.35	27	0.15	69	0.38	133	0.73	293	1.61
Oct.	--	--	--	--	--	--	--	--	--	--	--
Nov.	1,416	11	0.77	0	0	0	0	5	0.35	16	1.13
Dec.	1,200	9	0.75	5	0.42	0	0	20	1.67	34	2.83

The overall catch rate for all species reaches its maximum for the year in January with slightly under 4.5. The principal element in the catch is the spearfishes. There is a second peak when the catch rate increases from June to August. Here, too, the principal component of the catch is spearfishes. Yellowfin are most abundant in November and December, and their catch rate again increases in June to August. The bigeye tuna increase and decrease in roughly the same manner as the yellowfin, with their highest catch rate in January. No very regular changes in fishing conditions for albacore can be seen, but there are rather high catch rates in January, June, and September. Spearfishes are most abundant in December and January with fairly high catch rates also shown for the period from May through August.

Table 57 shows the situation for the area of 25° to 30° N. The overall total catch rate is at its maximum in January with slightly less than 11 percent. The greater part of the catch is albacore, other species being extremely scarce. From May through July the catch rates increase, with a catch rate of 4.57 in May. The principal species at this time are spearfishes, the other species being extraordinarily scarce. Some black tuna are taken in May and June. At other seasons there is a record of only one of this species in February. Yellowfin increase somewhat from May through August and from October through December, with the peaks in the catch rates in July and November. Bigeye tuna show roughly the same pattern of increase and decrease as the yellowfin, but the peak in the catch rates appearing in the summer is not very pronounced. Albacore are abundant from January through March, particularly in January, when the catch rate goes above 10.0. In the summer they are taken only very rarely. The principal fishing season for the spearfishes is from April through July.

Comparing tables 56 and 57, although there are differences in the values for the catch rates, the trends of increase and decrease are in good agreement. However, the conspicuous increase in the spearfishes shown for January in table 56 does not appear in table 57.

Comparing the area of 25° to 30° N., 130° to 140° E. shown in table 52 with the area shown in table 57, the patterns of changes in fishing conditions from month to month for each species, excepting the black tuna, are in extremely good agreement. The black tuna for the area shown in table 52 has a high catch rate from December through March. At this season in the area shown in table 57 almost none of this species are taken. It is thought worthy of note that from April through June, from the waters of the Okinawan archipelago on the west eastward to this sea area, black tuna are taken everywhere.

Table 57.--Fishing conditions by months (25° to 30° N., 140° to 150° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catc rate
Jan.	15,954	0	0	3	0.02	38	0.24	1,675	10.50	21	0.14	1,737	10.9
Feb.	37,898	1	0	22	0.06	67	0.18	1,198	3.16	249	0.66	1,537	4.06
Mar.	28,234	0	0	20	0.07	60	0.21	1,389	4.91	125	0.44	1,594	5.63
Apr.	548	0	0	0	0	0	0	0	0	11	2.01	11	2.01
May	15,486	5	0.03	44	0.28	0	0	0	0	652	4.21	701	4.57
June	13,959	4	0.03	51	0.37	4	0.03	1	0.01	328	2.35	388	2.79
July	3,632	0	0	25	0.69	4	0.11	0	0	60	1.65	89	2.45
Aug.	600	0	0	2	0.33	0	0	0	0	5	0.83	7	1.17
Sept.	4,140	0	0	7	0.17	1	0.02	1	0.02	9	0.22	18	0.43
Oct.	1,800	0	0	5	0.28	8	0.44	0	0	11	0.61	24	1.33
Nov.	780	0	0	6	0.77	2	0.26	1	0.13	1	0.13	10	1.29
Dec.	2,712	0	0	6	0.22	27	0.99	2	0.07	12	0.44	47	1.72

As the foregoing shows, in areas of about the same latitude, the changes in fishing conditions for each species from month to month are very similar, and this fact is an interesting indication in considering the migrational patterns of these fishes. It shows that in the sea area south of the Japanese sea islands, at any rate, it is difficult to think of these fishes as having any definite migrational paths.

Table 58 shows fishing conditions in this area divided up by 2° of longitude in order to compare the fishing from east to west.

Table 58.--Fishing conditions by sections (20° to 25° N., 140° to 150° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
140°-142°E.	19,982	0	0	87	0.44	18	0.09	21	0.11	146	0.73	272	1.37
142°-144°E.	25,931	0	0	68	0.26	31	0.12	11	0.04	234	0.90	344	1.32
144°-146°E.	25,361	0	0	46	0.18	20	0.08	17	0.07	270	1.07	353	1.40
146°-148°E.	26,655	0	0	110	0.41	81	0.30	52	0.19	372	1.39	615	2.29
148°-150°E.	19,690	0	0	55	0.28	42	0.21	40	0.20	207	1.05	344	1.74

For the yellowfin the local differences in fishing conditions are not marked. However, catch rates are somewhat higher from 140° to 142° E. and from 146° to 148° E. Local differences in bigeye catch rates are likewise not striking, but they appear to be higher in the east and lower in the west. Albacore also appear to exhibit a tendency to be high in the east and low in the west. The highest spearfish catch rates are in the section of 146° to 148° E.

Table 59.--Fishing conditions by sections (25° to 30° N., 140° to 150° E.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
140°-142°E.	14,180	2	0.01	45	0.32	29	0.20	35	0.24	191	1.34	302	2.11
142°-144°E.	59,085	8	0.01	94	0.16	90	0.15	1,057	1.79	865	1.45	2,114	3.56
144°-146°E.	41,886	0	0	47	0.11	68	0.16	1,551	3.70	419	1.00	2,085	4.97
146°-148°E.	16,173	0	0	4	0.02	22	0.13	1,492	9.22	17	0.11	1,535	9.48
148°-150°E.	990	0	0	0	0	0	0	80	8.08	1	0.10	81	8.18

Between 25° and 30° N., as table 59 shows, black tuna have been taken only in the section from 140° to 144° E. Yellowfin catch rates are highest in the west and tend to decrease gradually to the eastward, and similar trends appear for bigeye tuna and spearfishes. Albacore show the opposite trend, with catch rates low in the west and increasing gradually to the east.

In tables 58 and 59 no account at all is taken of the seasons, but it is clear from tables 56 and 57 that there are notable seasonal changes in fishing conditions. However, if the data in tables 58 and 59 are considered with attention to seasonal differences, these few data are further extended and diluted to the point where they do not have much significance. As tables 56 and 57 show, for the area from 20° to 25° N. there are more data for the summer (April to September) than for the winter (October to March). For 25° to 30° N., on the contrary, there are more data for the winter season, more than twice as much as for the summer, and this fact must be taken into consideration in comparing fishing conditions in the two areas.

Another problem which must be taken up together with the changes in the fishing conditions from season to season is that of the changes produced by differences in the fishing gear. This problem is not limited to only this sea area. The gear used in the winter north of 25° N. is mostly the so-called albacore line, and in view of its construction it goes without saying that some correction is necessary in order to judge the fishing conditions solely on the basis of catch rates. However, on the one hand, most of the data do not record the construction of the fishing gear and thus afford no clear basis for a correction, and on the other hand, as was set forth in Chapter 7, there is no accurate method of making such a correction. Consequently, in evaluating the fishing conditions for these species, and in considering the pattern of their distribution, the catch rates for yellowfin, bigeye tuna, and spearfishes north of 25° N. latitude cannot be said to have exactly the same significance as the catch rates south of that latitude. The same thing is true of the albacore. However, it is probably possible to discuss the patterns of distribution in terms of trends.

This sea area can be thought of as a comparatively stabilized fishing ground throughout the year. In the southern portion in December and January and for a few months in the summer the catch rates are high and the principal catch is spearfishes. In the northern part the catch rates are high from January through March and from May through July, with albacore the principal catch in the winter and spearfishes in the summer. Among the spearfishes taken in the summer striped marlin of 50 to 100 pounds predominate in the early part of the season. Thereafter the black marlin increase and at the peak of the fishing season, rather small black marlin of 80 to 160 pounds are most numerous. Many sharks, principally great blue sharks, are taken throughout the year, and at times they make up more than half the total catch.

(c) East of 150° E. (20° to 50° N.)

The only land in this area is Marcus Island at 24° 30' N., 154° E., and oceanographic conditions are comparatively uniform. The northern part of the area includes a part of the albacore grounds which extend on to the north and east and is an excellent ground for this species. The southern part, except for the vicinity of Marcus Island and on to the eastward, is almost a virgin fishing ground with few survey data, and its significance and value as a fishing ground are little known. The vicinity of Marcus Island is a fishing ground principally for spearfishes and yellowfin tuna, and the fishing situation there is in general similar to that of the Ogasawara Islands area.

The following table summarizes the survey data for this sea area.

Table 60.--Fishing conditions between 150° and 180° E. (20° to 30° N.)

Section	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
20°-25°N.	48,956	0	0	286	0.58	291	0.61	56	0.11	490	1.00	1,130	2.30
25°-30°N.	329,565	6	0	37	0.01	1,523	0.46	13,776	4.16	585	0.18	15,927	4.81
Total	378,521	6	0	323	0.09	1,821	0.50	13,832	3.65	1,075	0.28	17,057	4.51

The overall catch rate is slightly over 4.5. Fishing conditions north and south of 25° N. are very different, with spearfishes most abundant in the south followed by bigeye tuna and yellowfin. North of 25° N. albacore make up the majority of the catch. No black tuna have been taken in the southern part of the area, but some very scattered catches have been made in the northern part. Yellowfin are much scarcer in the northern part than in the southern part, there is no great difference in the abundance of bigeye, and albacore are extremely scarce in the southern portion, although they make up more than half of the catch in the northern part. The spearfishes are much less abundant in the northern part of this area.

If this is compared with the situation in the waters of the Ogasawara, Volcano, and Mariana islands described earlier, there are hardly any differences except that in the southern part the yellowfin and bigeye are quite a bit more abundant in this region. In the northern portion this area shows somewhat of a decrease in the number of yellowfin and spearfishes and a marked increase in bigeye. The albacore catch rate is also a little less than 1.0 per hundred higher in this sea area. It is a characteristic of this sea area that bigeyed tuna catch rates show a rather marked overall increase. However, it is thought that the reason for this is mainly the uneven seasonal distribution of the data.

Seasonal changes in fishing conditions cannot be determined accurately because the data are almost entirely limited to the winter. Changes in the fishing conditions from month to month for that part of the year for which data are available are presented in tables 61 and 62.

Table 61.--Fishing conditions by months (20° to 25° N., 150° to 180° E.)

Month	Number of hooks	Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	7,552	102	1.35	107	1.41	22	0.29	96	1.28	327	4.33
Feb.	15,681	108	0.62	113	0.72	22	0.14	246	1.56	489	3.12
Mar.	7,098	2	0.03	33	0.46	1	0.01	55	0.77	91	1.28
May	6,888	35	0.51	0	0	1	0.01	31	0.45	69	1.00
June	2,000	1	0.05	1	0.05	2	0.10	5	0.25	9	0.45
July	3,800	1	0.02	0	0	4	0.11	21	0.55	26	0.68
Nov.	1,953	26	1.33	18	0.92	0	0	3	0.15	47	2.40
Dec.	2,460	11	0.45	21	0.85	0	0	10	0.41	42	1.50

Table 62.--Fishing conditions by months (25° - 30° N., 150° - 180° E.)

Month	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	108,878	0	0	20	0.02	720	0.66	6,337	5.82	187	0.17	7,264	6.67
Feb.	86,723	1	0	10	0.01	502	0.58	3,142	3.62	160	0.19	3,815	4.40
Mar.	125,941	5	0	2	0	289	0.23	4,319	3.43	197	0.16	4,812	3.82
May	1,300	0	0	1	0.07	2	0.15	0	0	0	0.30	7	0.52
July	1,000	0	0	0	0	0	0	0	0	6	0.60	6	0.60
Dec.	2,996	0	0	2	0.07	5	0.17	2	0.07	32	1.07	41	1.38

In general the catch rate is low in the summer and high in the winter with the maximum in January. Although the data can hardly be said to be adequate, the yellowfin catch rate for November and January is over 1.0. The bigeye fluctuate in approximately the same fashion as the yellowfin. Albacore have their peak catch rate in January; spearfishes are most abundant from January through March with their peak in February. Data for the summer are inadequate, but it appears that catch rates increase from May through July.

If this is compared with the southern part of the Ogasawara Islands area (see table 56), the trends of increase and decrease for the yellowfin are roughly in agreement, although the catch rate values are different. Bigeye tuna and albacore are also quite similar, and approximately the same sort of trend is shown for the spearfishes.

Table 62 shows changes from month to month in the fishing conditions in the northern section (25° to 50° N.).

Fishing is good from December on, with the highest catch rate in January. During February and March catch rates fall off gradually. For the summer there are only a few data for May and July and no sort of analysis can be given with just these data, however they appear to show that fishing is extremely poor.

Considering the individual species, black tuna are taken very rarely in February and March; yellowfin appear to be taken throughout the year but in such numbers that it is hardly worth while discussing their significance in the catch. Bigeye tuna have their highest catch rate in January, are still fairly abundant in February, and thereafter gradually decrease. Albacore suddenly become abundant in January and continue to show rather high catch rates in February and March, but they appear to be taken hardly at all in the summer. The spearfishes show their highest catch rate of the year in December. From January to March they continue to be taken with no great changes in their catch rates. It appears that their catch rate again tends to increase in the summer, but as there are very few data it is difficult to describe the situation accurately.

If we compare the foregoing with conditions in the southern part of the sea area, the trends of increase and decrease are in agreement, although there are differences in the catch rate values for yellowfin, bigeye, albacore, and spearfishes. However, in the case of the spearfishes there is a difference in the month in which the peak catch rate appears in the winter, this being earlier (December) in the north and later (February) in the south.

Comparing table 62 with table 57 (northern part of the Ogasawara Islands area), the trends of seasonal fluctuations in the catch rates are very similar, but the peaks in the catch rate in the Ogasawara area appear to be generally about one month earlier.

The following table shows changes in fishing conditions with longitude.

Table 63.--Fishing conditions by sections (20° - 25° N., 150° - 180° E.)

Section	Number of hooks	Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
150°-152°E.	18,072	29	0.16	62	0.34	4	0.02	219	1.21	314	1.73
152°-154°E.	8,864	59	0.66	25	0.28	3	0.03	65	0.73	152	1.70
154°-156°E.	16,220	196	1.21	210	1.29	43	0.26	172	1.06	621	3.82
162°-164°E.	1,000	1	0.10	1	0.10	0	0	1	0.10	3	0.30
166°-168°E.	1,700	1	0.06	0	0	2	0.12	7	0.41	10	0.59
168°-170°E.	700	0	0	0	0	1	0.14	5	0.71	6	0.85
170°-172°E.	2,400	0	0	0	0	3	0.12	13	0.54	16	0.66

The catch rates are highest in the section between 154° E. and 156° E. In the sections farther to the west they are about 1.7, while to the eastward the rates are very low. Both yellowfin and bigeye are most abundant between 154° and 156° E., while spearfishes are most abundant in the extreme western part, with rather high catch rates centering around 155° E. This fact is thought to indicate that the vicinity of Marcus Island is a fairly good fishing ground for this species.

If changes in the fishing conditions resulting from the uneven seasonal distribution of the data are ignored, the highest catch rates are shown for the sections centered on 155° E., 165° E., and 175° E. Taking up the species individually, yellowfin are taken rarely throughout the whole area and it is difficult to recognize any local variations in the catch pattern. Bigeye show a tendency to be somewhat more abundant in the vicinity of 160° E., 165° E., and 175° E. Albacore are the most important element in the catch throughout the whole area, and the local variations in their catch rates agree perfectly with those of the total catch rate. Their pattern is also in rough agreement with that for the bigeye tuna. Spearfish catch rates are somewhat higher in the extreme western portion, that is, near to Japanese waters, and they appear to present roughly equal catch rates from the vicinity of 160° on eastward. South of 25° N. the data are scarce and are completely lacking for many sections, so it is almost impossible to make any comparison between the northern and southern parts of the area.

Table 64.--Fishing conditions by sections (25° - 30° N., 150° - 180° E.)

Section	Number of hooks	Yellowfin		Bigeye		Albacore		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
150°-152°E.	2,946	2	0.07	5	0.17	36	1.22	23	0.79	66	2.25
152°-154°E.	12,825	2	0.02	21	0.16	312	2.43	82	0.64	417	3.25
154°-156°E.	5,726	1	0.02	2	0.03	223	3.89	22	0.38	248	4.32
156°-158°E.	4,239	0	0	8	0.19	21	0.49	3	0.07	32	0.75
158°-160°E.	1,918	0	0	1	0.05	7	0.36	5	0.25	13	0.66
160°-162°E.	7,320	0	0	48	0.66	85	1.16	16	0.22	149	2.04
162°-164°E.	8,270	2	0.02	9	0.11	152	1.85	16	0.18	179	2.16
164°-166°E.	10,420	7	0.07	65	0.62	617	5.92	17	0.16	706	6.77
166°-168°E.	4,631	0	0	13	0.28	138	2.98	8	0.17	159	3.43
168°-170°E.	23,128	0	0	65	0.28	809	3.50	19	0.08	893	3.86
170°-172°E.	39,714	0	0	97	0.24	1,651	4.16	37	0.10	1,785	4.50
172°-174°E.	53,762	16	0.03	351	0.65	2,701	5.02	41	0.08	3,109	5.78
174°-176°E.	96,908	3	0	758	0.78	5,346	5.52	199	0.21	6,306	6.51
176°-178°E.	21,326	4	0.02	39	0.18	732	3.43	44	0.21	817	3.84
178°-180°E.	36,432	0	0	41	0.11	946	2.60	53	0.14	1,040	2.89

As mentioned earlier, data for the southern part of the area are almost limited to the vicinity of Marcus Island. Data for the northern part are generally distributed, however, seasonally they are restricted to the winter. Consequently we are not able on the basis of these data to clarify completely the total significance which the central subtropical Pacific sea area has as a fishing ground. Nevertheless, if we tally all the facts recorded above, it is clear that the whole area to the east of 150° E. longitude in the western Pacific subtropical zone may have a uniform significance and value as a fishing ground. As was stated earlier, the subtropical convergence runs east and west through this area, and north and south of that convergence the current systems and the significance of the fishing grounds are quite different. That is, to the south the principal components of the catch are yellowfin, bigeye tuna, and spearfishes, while to the north the main catch is albacore. However, at some seasons bigeye tuna may also be extremely important.

For the western Pacific subtropical sea area as a whole, it appears that there is, in addition to the north-south difference on either side of the subtropical convergence, a difference from east to west. This east-west difference is largely determined by the topography or the presence of islands, and in this sense the area may be divided into the Okinawa-Ogasawara-Volcano Islands region and the waters to the east of it, each having its own characteristics as a fishing ground. As will be related later, the distributional patterns of tunas and spearfishes quite definitely differ around the Izu and Ogasawara islands, and it is known that for some species the fishing conditions may differ markedly in the waters to the east and west of these islands.

11. Nankai sea area (30° to 35° N., 130° to 140° E.)

The waters from south of Kyūshū to off the Bōsō Peninsula, from 30° to 35° N., will be described under the provisional designation of Nankai sea area.

This area is almost entirely within the Kuroshio current, with the current flowing constantly east or northeast along the coast of Japan. The so-called Kuroshio Countercurrent appears off the Kii peninsula and east of the Izu Islands.

Table 65 shows the oceanographic conditions in this area based on considerable data. The water color is generally II or III on Forel's scale, and transparencies are low, about 20 meters.

The extreme western part of this area in the vicinity of Tanegashima is famous as a black tuna fishing ground, but in recent years no fish have been taken at all and no boats have been operating there. The fishing season was limited to the winter, beginning around December and with the peak of the season in January and February. The main base for this fishery was the port of Aburatsu in Miyazaki Prefecture, and the amount of landings and changes in the size of fish for a number of years at that port are shown in figure 12.

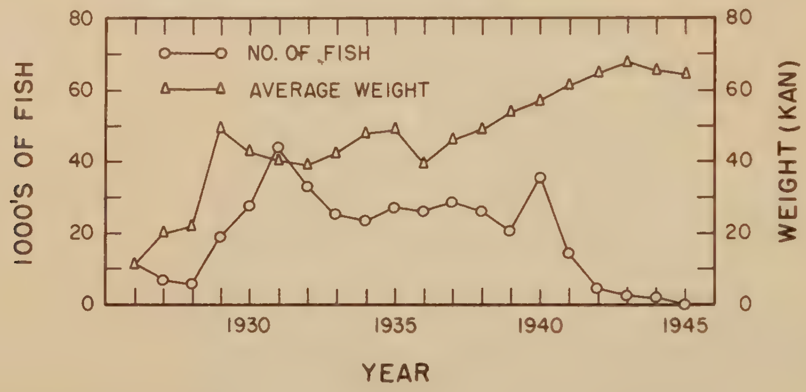

Figure 12.--Annual changes in black tuna landings and average weight at Aburatsu

Table 65.--Oceanographic conditions in the vicinity of 32° N., 133° 30' E.

Month	Temperature (°C.)			Salinity		
	0 m	50 m	100 m	0 m	50 m	100 m
Feb.	17.7	17.0	16.0	34.85	34.92	34.79
May	21.7	19.3	17.2	34.76	34.85	34.63
Aug.	27.7	26.7	23.8	34.11	34.14	34.56
Nov.	24.6	24.6	24.6	34.69	34.65	34.65

It is clear from the figure that a rapid increase in the number of black tuna landed at Aburatsu began in the early years of the Shōwa Era, the peak being reached in 1931 with landings of about 43,000 fish. From 1932 through 1933 there was a gradual decline, and then the landings continued without much change at around 20 to 30 thousand fish from 1933 to 1939. There was a fairly marked increase to 35,000 fish in 1940. From 1941 on the catch fell off steeply, and from 1945 to the present there has been hardly any catch at all.

As for the size of the fish, the average weight in 1927 and 1928 was around 165 pounds, in 1929 this suddenly increased to about 396 pounds. From 1930 to around 1938 the average weight fluctuated between 331 and 410 pounds. From 1939 on the fish increased in size from year to year and after 1942 the average was about 496 pounds.

Table 66.--Oceanographic conditions in the vicinity of 30° N., 134° 30' N.

Month	Temperature (° C.)			Salinity		
	0 m	50 m	100 m	0 m	50 m	100 m
Feb.	18.7	18.5	18.5	34.90	34.83	34.88
May	23.5	21.6	20.2	34.72	35.01	34.87
August	29.0	24.4	21.1	34.56	34.63	34.85
Nov.	24.6	24.6	23.3	34.54	34.69	34.78

Table 67.--85 miles south by east of Gozamisaki

Month	Temperature (° C.)			Salinity		
	0 m	50 m	100 m	0 m	50 m	100 m
Feb.	17.7	17.9	17.5	34.88	34.94	35.01
May	19.0	16.3	15.0	34.52	34.74	34.76
Aug.	27.3	18.2	16.0	34.16	34.49	34.49
Nov.	22.8	20.6	17.2	--	--	--

From the foregoing it appears that during the period when the fishery was in a stabilized condition, with no great difference in the number of fish taken from year to year, there were schools made up of approximately the same sizes of fish migrating into the grounds every year at a more or less definite season. However, as the size of these migrating fish increased, their numbers declined abruptly, and finally a condition was brought about where no fish were taken at all.

As explained in the foregoing, hardly any black tuna are now taken, but a certain number of bigeye tuna and spearfishes are caught at present, the bigeye tuna being the most important.

In the west coast waters of Kyūshū, which adjoin this sea area on the west, the catch is almost entirely composed of spearfishes. The fishing ground for the most part is along the 100-fathom line in the East China Sea. The best known fishing ground is in the vicinity of Saishū Tō (Quelpart Island), but some fish are also taken across the Tsushima Strait in the southern part of the Sea of Japan. In August and September the fishing grounds are centered around Saishū Tō, but thereafter with the passage of time they gradually shift to the southward.

Spearfishes are abundant from the waters around Tanegashima north to the region of the Hyūga Nada, and the harpoon fishery in this area is at its peak from April through June. Farther to the eastward, between the waters of Tosa and the Kishū region, the black tuna catch declines sharply and albacore become the most important item in the catch. Next to the albacore, bigeye tuna are the most abundant, and at certain seasons some yellowfin and spearfishes are taken. Farther to the eastward in the Izu Islands region, the makeup of the catch is again different, spearfishes being the most important element in the catch here and surpassing the tunas.

Thus the composition of the catch is different in the different sea areas, and fishing is carried on using gear of different construction. It may be thought that the differences in the catch are due to the differences in the construction of the gear, but the actual truth is probably that differences in the distribution of the species have brought about the changes in the construction of the fishing gear. The foregoing refers only to the longline fishery, and in actuality rather large numbers of albacore and young yellowfin, bigeye, and black tuna are taken by pole and line fishing, while the catch of fixed gear in some years is by no means small.

Table 68 summarizes data from the surveys which have been carried on in the Nankai sea area.

Table 68.--Fishing conditions in the Nankai sea area

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
815	257,001	807	0.31	106	0.04	745	0.29	4,754	1.84	622	0.24

The overall average catch rate is slightly over 2.7. From 60 to 70 percent of the catch is albacore, followed by black marlin and bigeye tuna. Yellowfin are almost without significance as an objective of the fishery.

If this area is divided into sections of 2° of longitude, and the fishing situation for each of these sections is plotted, we get the following curves (figure 13).

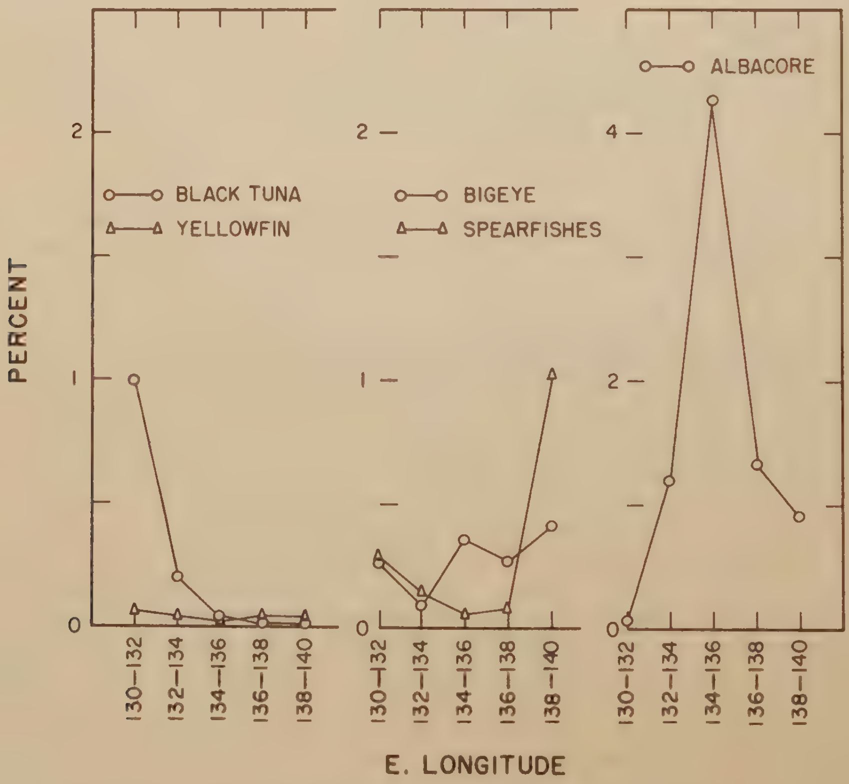

Figure 13.--Catch rates by 2° sections (30° - 35° N., 130° - 140° E.)

As the figure clearly shows, black tuna have a catch rate of slightly under 1.0 in the section from 130° to 132° E. longitude, but farther to the east the decline in the catch rate is extremely conspicuous. The yellowfin catch rate is very low with little difference throughout the whole area. The bigeye tuna decrease somewhat in the section between 132° and 134° E. longitude, and tend to increase steadily to the eastward. Spearfishes decrease gradually from the extreme west toward the central portion, then increase sharply in the vicinity of the Izu Islands until the catch rate is slightly over 1.0. Albacore show a conspicuous increase in the central part of the area, where the catch rate is 4.2.

In the extreme western section around Tanegashima black tuna are the most important element in the catch, in the central part around the Kinan Shoals albacore are the main species, and in the far eastern section around the Izu Islands spearfishes make up the greater part of the catch. This situation is very clearly shown by the figure.

In order to see the seasonal changes in the fishing, catches for each month have been shown in table 69. The inequality in the seasonal distribution of the data is very great, and for this reason it is difficult to grasp fully the changes from month to month in fishing conditions. Leaving aside all considerations of areas and summarizing the data for this sea area as a whole, it is shown that black tuna are more abundant in the winter, with their highest catch rates for the year from March through April. Yellowfin are generally scarce, but they increase somewhat around April and then have their highest catch rates for the year from October through November. Bigeye tuna are not taken at all during the summer, their highest catch rate for the year being in October, after which they gradually decline. Albacore are hardly taken at all during the summer; their catch rates gradually improve from December to February, after which they decrease suddenly in March.

The foregoing is based exclusively on the longline fishery with no consideration of the pole-and-line fishery. The pole-and-line catch is fairly large at certain seasons, but the fish taken are generally small.

In addition the fishery with fixed gear takes some yellowfin and black tuna, and the catch in certain years is fairly considerable. The fishing season for these fisheries is mainly in the summer.

The situation is not entirely clear because there are very few data for July and none at all for August and September, but it is shown that in general spearfishes are abundant in the summer, with a truly high catch rate of 6.8 in June, showing that considerable catches can be anticipated. This high catch rate is based on data obtained almost entirely from the waters adjacent to the Izu Islands. There are no data for other parts of the area so they cannot be shown, but it appears that in recent years a large number of harpoon boats have operated in the Hyūga Nada area with fairly good success, the season extending from 2 to 3 months centered around May.

Fishing for spearfishes in the Ogasawara Islands area, which adjoins the Izu Islands area on the south, is, as has already been stated, good from April through July in the northern section (25° to 30° N.), with the catch rate reaching a high in May of 4.2. Consequently it is thought that there is a lag of about 1 month between the peak of the spearfish season in the northern Ogasawaras and the waters adjacent to the Izu Islands.

As was stated earlier, in the winter the central part of this region produces a large albacore catch, and in the most westerly part the black tuna fishery is at its peak. In the summer there is a general tendency for the spearfish catch to increase markedly, this trend being particularly conspicuous in the waters adjacent to the Izu Islands. However, the fishing season is short. From October on there is some increase in the yellowfin and bigeye catch.

The overall catch rate throughout the year is shown to be slightly more than 2.7, but if the distance between the bases and the fishing grounds is taken into consideration, it is not correct to say that the grounds of this sea area are very inferior. Besides the tuna and spearfishes, an equal or greater number of sharks are taken and considerable numbers of other miscellaneous fish are also captured, so it is believed that if no error is made in selecting a fishing ground and if consideration is given to the season, the grounds of this area present quite advantageous conditions for medium-sized and small vessels.

Table 69.--Fishing conditions by months (Nankai sea area)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	128	73,843	209	0.28	22	0.03	244	0.33	1,761	2.39	72	0.10
Feb.	293	81,460	366	0.45	10	0.01	177	0.22	2,430	2.98	186	0.22
Mar.	210	40,809	266	0.65	12	0.03	52	0.13	347	0.85	117	0.29
Apr.	23	1,014	29	1.51	5	0.26	1	0.05	0	0	3	0.15
May	11	3,704	3	0.08	2	0.06	0	0	0	0	70	1.89
June	9	1,764	0	0	1	0.05	0	0	2	0.11	120	6.80
July	2	800	0	0	1	0.12	0	0	0	0	4	0.50
Aug.	--	--	--	--	--	--	--	--	--	--	--	--
Sept.	--	--	--	--	--	--	--	--	--	--	--	--
Oct.	15	3,500	0	0	13	0.37	36	1.03	0	0	7	0.20
Nov.	27	10,249	1	0.01	24	0.23	52	0.51	15	0.15	8	0.08
Dec.	86	39,511	12	0.03	17	0.04	160	0.40	434	1.10	30	0.08

The Tanegashima area in the extreme western part of this region is famous as a black tuna ground, but at present it has almost entirely lost its significance and value as a fishing ground for this species. It is thought, however, that this condition is probably the result of cyclical changes in oceanographic conditions, and it is anticipated therefore that in the future it will recover its value as a fishing ground.

12. Area east of the Izu Islands (30° - 35° N., 140° - 150° E.)

The area from 30° - 35° N., 140°- 150° E. will be described under the designation "sea area east of the Izu Islands."

There are some fluctuations in the currents from year to year depending on the difference in the strength of the Kuroshio, but the greater part of this area is within the Kuroshio Countercurrent. The main stream of the Kuroshio flows along the northern edge of the area in a roughly easterly direction. As the subtropical convergence runs east and west at about the line of 30° N. latitude during the summer, there is in this area as a whole a clockwise gyral formed by the current flowing northward from the Ogasawara Islands region, the Kuroshio, and the Kuroshio Countercurrent. In the winter the subtropical convergence gradually moves southward and around February and March it is in the vicinity of 24° - 25° N. Because of this the south-eastward- or south-southeastward-flowing Kuroshio Countercurrent becomes more prominent in this sea area.

Table 70 shows oceanographic conditions in this sea area on the basis of data gathered on the cross-sectional observation line southeast of Cape Nojima. In February the heart of the Kuroshio is about 50 to 80 miles off the coast and the surface water temperature is about 20° C. Farther off shore the temperature is down to 17.3° C. around 100 miles from the coast, while in the vicinity of 120 miles off shore there is a zone of fairly warm water of 18° C. to 19° C. Farther off shore the water temperature again goes down to 17° C., continuing at this level to the vicinity of 260 miles off the coast. At 300 miles off shore the water temperature rises a little to above 18° C. Water temperature is approximately the same from the surface through the 100-meter level, showing that mixing is being carried on by convection currents.

Table 70.--Oceanographic conditions southeast of Cape Nojima

Month	Depth (meters)	50 miles		80 miles		100 miles		200 miles		300 miles	
		Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
Feb.	0	19.4	34.81	20.0	34.81	17.3	34.83	17.4	34.83	18.1	34.81
	50	19.4	35.25	19.7	34.83	17.3	34.74	17.4	34.74	17.7	34.79
	100	19.0	34.97	19.7	34.87	17.3	34.79	11.4	34.76	17.7	34.87
	200	18.2	34.88	18.3	34.85	17.3	34.76	17.4	34.85	17.6	34.83
May	0	20.7	33.35	20.1	34.13	18.7	34.23	18.4	33.89	19.7	34.76
	50	20.3	34.31	20.1	33.64	18.7	33.87	17.8	34.27	17.8	34.52
	100	19.7	33.96	18.3	34.02	17.8	32.38	17.0	34.23	17.1	33.79
	200	18.3	34.29	17.8	34.14	17.3	32.94	16.8	34.31	16.8	33.66
Aug.	0	28.5	34.54	27.8	34.38	28.0	34.33	27.6	34.43	27.4	34.42
	50	25.2	34.81	24.4	34.45	22.4	34.54	22.6	34.42	22.4	34.45
	100	22.2	34.88	20.8	34.06	21.8	34.78	20.8	34.38	20.7	34.33
	200	21.1	34.87	19.6	34.63	21.4	34.81	18.6	34.52	20.7	34.49
Nov.	0	24.2	34.58	22.6	34.52	22.7	34.47	23.7	34.69	23.8	34.49
	50	23.8	34.56	22.0	34.74	22.4	34.49	22.5	34.69	22.5	34.34
	100	22.7	34.60	20.8	34.87	20.4	34.85	21.5	34.72	21.5	34.65
	200	20.6	34.85	19.6	34.79	19.2	34.87	18.8	34.76	18.8	34.87

Note: (1) The distances are shown from Cape Nojima as a starting point.

(2) This table is drawn from the Records of Oceanographic Investigations for 1937.

In May the zone with the highest water temperature is 50 miles off shore, where 20.7° C. is shown. From here on out to the 200-mile line temperatures gradually fall to between 18° and 19° C. In the vicinity of the 300-mile station they rise somewhat to 19.7° C. If one looks at the vertical distribution of the water temperatures, the tendency toward stratification is clear.

In August the coastal waters are up to 23° to 24° C., and the area of highest water temperatures is about 40 miles off shore, where the surface water temperature is 28.6° C. From 70 miles off shore on out the water temperatures are from 27° to 28° C., and the temperatures are at their lowest in the vicinity of 250 to 300 miles off shore.

In November the zone of highest water temperatures appears between 20 and 40 miles off shore with surface water temperatures of 24.6° C. From 80 to 180 miles off the coast the water temperatures are between 22° and 23° C., and from 200 miles off the coast on out the temperatures are from 23° to 24° C.

In the off-shore water the transparencies are highest in the summer, when the waters are stratified, with values of 25 to 28 meters. In winter, which is the season of convection, values are low, being about 17 to 20 meters. As for water color, II on Forel's scales generally most frequent, with III observed quite often.

This sea area is a part of the so-called winter albacore grounds, which extend on to the eastward. The fishing season is, of course, during the winter. At some seasons considerable numbers of bigeye tuna are taken. In the summer spearfishes, principally the striped marlin, are taken, and from late autumn to early winter considerable numbers of broadbill swordfish are caught.

Table 71 summarizes the data from surveys which have been made in this sea area.

Table 71.--Fishing conditions in the sea area east of the Izu Islands (30° to 35° N., 140° to 150° E.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
485	328,452	48	0.01	39	0.01	824	0.25	13,649	4.13	2,187	0.67

The overall average catch rate is slightly more than 5.0. The biggest catch is the albacore, making up more than 80 percent of the whole. Next to the albacore most important are the spearfishes, with the black tuna and yellowfin of little significance. Bigeye tuna have a catch rate little different from that of the Nankai sea area adjacent on the west.

In table 72 this area is divided into five equal parts of 2° of longitude each, and the fishing situation for each of these sections is shown separately.

Table 72.--Fishing conditions by longitude (sea area east of the Izu Islands)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
140°-142°E.	234	141,155	7	0.01	11	0.01	378	0.27	2,971	2.10	1,414	1.00
142°-144°E.	85	68,999	7	0.01	12	0.02	159	0.23	3,476	5.04	300	0.43
144°-146°E.	61	50,224	1	0.00	5	0.01	85	0.17	2,630	5.25	182	0.36
146°-148°E.	47	38,298	10	0.03	7	0.02	102	0.27	2,274	5.94	134	0.35
148°-150°E.	58	39,866	23	0.06	4	0.01	150	0.37	2,298	5.86	155	0.39

Looking at this sea area as a whole, with no consideration given to seasonal changes in fishing conditions, there is a tendency for black tuna to be more abundant farther off the coast. Yellowfin are vestigial, but they are taken quite uniformly, while bigeye tuna appear to show a tendency to be somewhat less numerous in the central part and more abundant at the eastern and western extremities, however, this tendency is not very conspicuous. Albacore are remarkably scarce in the most westerly part and tend to increase in numbers to the eastward. Spearfishes are abundant in the coastal waters of the Izu Islands and scarcer off shore and they are taken rather uniformly in the off-shore waters, with no great local variations in the catch.

Ignoring local variations in the fishing conditions, table 73 shows the fishing conditions by months for the whole sea area. There are very few data for the summer, so seasonal changes in fishing conditions are not clear, but within the scope of the table the fluctuations are approximately as follows. Catches of black tuna are recorded only for the months of January, February, and April. A few yellowfin are taken in each month throughout the year, and they appear to become somewhat more abundant around July and August. Highest catch rates for bigeye tuna appear in April, and they are generally abundant in December and January. Hardly any albacore are taken in the summer, the first catches being made in November with a rapid increase to January, which has the highest catch rate of 5.9. In February the catch rate drops somewhat from January, but it is still slightly over 5.0. From March on the catch rate falls off steeply. The spearfishes show a peak in their catch rate from June through July. In the winter catch the broadbill is most important; striped marlin and black marlin are most numerous in the summer.

Table 73.--Monthly fishing conditions (sea area east of the Izu Islands)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	151	100,163	33	0.03	8	0.08	327	0.33	5,973	5.90	610	0.61
Feb.	177	125,087	10	0.01	15	0.01	320	0.26	6,586	5.26	868	0.70
Mar.	84	49,172	1	0.00	4	0.01	120	0.24	843	1.71	496	1.01
Apr.	19	9,326	3	0.03	3	0.03	60	0.64	85	0.91	35	0.38
May	1	480	0	0.00	0	0.00	1	0.20	5	1.04	0	0.00
June	1	184	0	0.00	0	0.00	0	0.00	0	0.00	10	5.43
July	9	1,790	0	0.00	3	0.17	3	0.17	0	0.00	50	2.80
Aug.	6	1,142	0	0.00	4	0.35	0	0.00	0	0.00	8	0.70
Sept.	--	--	--	--	--	--	--	--	--	--	--	--
Oct.	1	420	0	0	0	0	0	0	0	0	5	1.19
Nov.	7	6,510	0	0	1	0.02	11	0.19	51	0.78	33	0.51
Dec.	34	15,840	0	0	1	0.01	47	0.30	577	3.71	87	0.55

Table 74 shows the seasonal and local distribution of the data.

As is shown in table 73, the greater part of the catch in the summer is spearfishes. It is clear from table 74 that the area from which the spearfishes are taken during the summer is restricted to the western part of the sea area, that is the vicinity of the Izu Islands, the situation in the off-shore waters being unclear because of the complete lack of data.

As for the winter season, when albacore are the main element in the catch, there are approximately uniform catch rates throughout the whole sea area in February, somewhat higher values being shown only for the section from 146° to 148° E. In December and January there are large local variations in the catch rates, and these variations show no definite trend. In March the catch rate is slightly over 4.0 in the extreme western section, but elsewhere in the more off-shore waters the catch rates generally go down steeply and the significance of the area as a fishing ground is diminished.

If fishing conditions in this area are compared with those in the Nankai sea area adjacent on the west:

1. The catch of black tuna is much less in this sea area.
2. The catch of albacore is much greater in this area.

3. Spearfishes are somewhat more abundant in this area, yellowfin are more abundant in the Nankai sea area, and there is almost no perceptible difference in bigeye tuna.
4. As for changes in fishing conditions from month to month, in the case of the most important species, the spearfishes and albacore, it appears that the fluctuations in fishing conditions show almost identical trends in the two sea areas. However, it appears that the peak of the albacore season is somewhat later in the Nankai sea area than in this area.
5. The highest catch rate for bigeye tuna in the Nankai sea area occurs in October, and it is difficult to make a comparison with this sea area because of the paucity of data.
6. The east and west sides of the Izu Islands show almost the same catch rates for spearfishes, but the species are not necessarily the same, as will be explained later.

It is observed that the fishing grounds to the east and west of the Izu Islands are not quite the same in character but have somewhat different characteristics.

Table 74.--Distribution of the data by months and areas (sea area east of Izu Islands)

Month	140° - 142° E.			142° - 144° E.			144° - 146° E.			146° - 148° E.			148° - 150° E.		
	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate
Jan.	38	18,988	3.27	15	12,165	10.88	31	27,648	7.24	19	14,426	5.43	38	26,886	8.07
Feb.	103	53,799	5.30	34	37,436	5.21	14	12,964	5.74	19	18,072	8.39	5	2,390	3.56
Mar.	47	25,626	4.12	21	14,480	1.85	12	6,966	1.75	3	1,800	0.89	1	300	1.00
Apr.	11	5,960	2.70	--	--	--	4	6,966	1.75	3	1,080	0.92	1	360	0.56
May	--	--	--	1	480	1.25	--	--	--	--	--	--	--	--	--
June	1	184	5.43	--	--	--	--	--	--	--	--	--	--	--	--
July	3	600	2.00	6	1,198	2.65	--	--	--	--	--	--	--	--	--
Aug.	3	542	0.92	3	600	1.17	--	--	--	--	--	--	--	--	--
Sept.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oct.	1	420	1.19	--	--	--	--	--	--	--	--	--	--	--	--
Nov.	--	--	--	1	402	0	5	2,597	1.12	4	2,910	1.17	25	16,600	1.84
Dec.	18	6,780	1.00	5	2,640	13.41	2	1,160	2.70	5	2,920	6.88	4	2,340	2.52

Note: The catch rate is combined for tunas and spearfishes.

If this sea area is further compared with the northern part of the waters adjacent to the Ogasawara archipelago on the south,

1. There is no great difference in the black tuna catch rates.
2. Yellowfin are somewhat less numerous in this sea area.
3. Bigeye tuna are somewhat more abundant in this sea area.
4. Albacore catch rates show values of about 1.0 per hundred higher in this sea area.
5. Spearfishes are somewhat less abundant in this sea area.

6. Variations in fishing conditions with longitude coincide completely in their trends, although there are some differences in the actual catch rate values.
7. The changes from month to month in fishing conditions for each species are also similar, but it looks as if the peak season for spearfishes is about 1 month later in this sea area.

The facts listed above show that this sea area is more closely related to the area adjacent to the south than to that on the west. In addition to the tunas and spearfishes there is a considerable catch of sharks, and therefore it can probably be said that, aside from the slack seasons of spring and autumn, this sea area affords rather good fishing grounds for small and medium boats. In the summer, besides the longline fishery, a harpoon fishery for spearfishes and pole-and-line fishing for small tuna and albacore are carried on. The weather, as is generally known, is extremely calm in the summer except when typhoons are originating. During the winter strong westerly winds blow continuously and the sea becomes quite rough with consequent difficulty in operating.

13. Northeastern sea area (35° N., 140° to 150° E.)

The area north of 35° N. latitude and between 140° and 150° E. longitude will be described as the northeastern sea area. Its northern boundary is in the vicinity of 42° N.

At the height of summer a part of the Kuroshio flows northward or north-northeastward from the vicinity of Inubō Misaki and passes through this sea area. The Oyashio flows southwestward from the Kurile Islands area in a direction roughly opposite to that of the Kuroshio. This current generally becomes submerged, but here and there it flows in wedge-shaped tongues into the Kuroshio. Also at times parts of the warm or cold currents get cut off from the currents of origin and become isolated water masses within different currents. Very close to the coast in the Sanriku area of northeastern Japan a tail end of the Tsushima Current, which has come through the Tsugaru Strait, flows southward. In the winter the strength of the Oyashio increases and it forces the Kuroshio southward so that the influence of the Kuroshio does not extend to the northward, but is deflected eastward into the central Pacific. The tail end of the Tsushima Current which has come through the Tsugaru Strait flows weakly south along the coast.

The foregoing is an outline of the distribution of ocean currents in this sea area, but because of this clash of sea currents of completely different character and because of the annual or seasonal differences in their strength, there are rather conspicuous fluctuations in oceanographic conditions from year to year, and in many cases there are violent short-term fluctuations so that the situation is a great deal more complicated than in the tropical and subtropical regions.

The following tables present oceanographic data for this sea area abstracted from the Report of Oceanographic Works for 1937.

As the table shows, the distribution of water temperatures in January is approximately uniform up to about 100 miles off the coast with temperatures of about 10.5° C., and with almost no change from the surface to the 100-meter level. In the vicinity of 150 miles off shore the water temperatures fall rather conspicuously to 8.6° C. at the surface and 8.1° C. at the 100-meter level.

In February the water temperatures are everywhere conspicuously lower, falling 2° to 4° C. At a point 50 miles off the coast the water temperatures at all levels from 10 meters on down are conspicuously lower than those at other points. At the station 150 miles off the coast just as in January the values are low at all levels.

Table 75.--Transverse sectional observations directly east of Same

Month	Depth (meters)	10 miles		20 miles		50 miles		80 miles		100 miles		150 miles	
		Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity
Jan.	0	10.5	33.41	10.6	33.17	10.7	33.18	10.5	33.34	10.6	33.19	8.6	32.94
	10	10.4	34.69	10.4	33.04	10.6	33.19	10.5	33.20	10.5	33.13	8.6	33.04
	25	10.3	33.41	10.3	33.12	10.5	33.17	10.5	33.08	10.4	33.13	8.6	33.06
	50	10.3	33.41	10.3	33.12	10.6	33.12	10.4	33.12	10.5	33.19	8.5	33.02
	100	--	--	10.3	33.17	10.6	33.19	10.4	33.12	10.5	33.17	8.1	33.12
Feb.	0	8.6	32.03	8.0	32.74	8.0	33.64	8.5	33.95	8.0	33.71	7.6	33.68
	10	8.5	33.57	7.4	33.68	6.5	33.58	8.0	33.57	7.9	33,58	7.5	33.75
	25	8.5	33.64	7.7	33.65	6.5	33.58	7.9	33.75	8.0	33.77	7.5	33.75
	50	8.5	32.39	7.7	33.53	6.6	33.57	8.0	33.75	8.1	33.75	7.3	32.63
	100	--	--	7.5	33.68	6.4	33.55	7.9	33.75	8.0	33.75	7.3	33.77
Mar.	0	7.3	33.22	7.3	33.91	5.8	33.55	7.5	33.86	8.1	34.02	6.6	33.77
	10	7.3	33.93	7.3	33.93	5.7	33.57	7.3	33.84	8.0	33.96	6.5	33.51
	25	7.4	33.91	7.4	33.89	5.7	33.60	7.4	33.86	8.0	33.95	6.5	33.69
	50	7.4	33.93	7.5	33.89	5.6	33.51	7.3	33.84	8.0	34.00	6.5	33.68
	100	--	--	7.1	33.80	5.4	33.42	7.5	33.98	7.9	34.02	6.5	33.75
Apr.	0	7.9	34.14	7.6	33.75	9.8	34.58	1.7	33.01	8.5	33.73	--	--
	10	7.5	34.11	7.4	33.61	9.6	34.60	2.0	32.09	8.5	34.69	--	--
	25	7.4	34.34	7.4	33.86	9.8	34.73	3.8	33.17	8.5	34.07	--	--
	50	7.2	34.23	7.3	33.61	9.8	34.22	3.5	32.63	7.6	34.81	--	--
	100	--	--	7.3	33.75	9.6	34.06	4.2	33.18	5.8	33.47	--	--
May	0	9.2	33.86	9.1	33.66	8.0	33.31	8.4	33.33	8.0	32.28	9.4	34.00
	10	9.2	33.75	9.1	33.69	8.3	33.53	8.3	35.58	7.8	33.24	9.4	34.02
	25	9.1	33.80	9.1	33.75	8.0	33.44	8.2	33.57	7.9	33.48	9.4	34.05
	50	9.0	33.80	9.1	33.77	6.0	33.39	8.6	33.95	7.2	33.55	9.2	--
	100	--	--	8.9	33.86	5.9	33.55	7.7	33.77	3.5	33.35	9.0	34.07
June	0	12.5	33.49	12.6	33.42	12.0	33.44	13.5	33.31	13.0	34.02	--	--
	10	12.0	33.41	11.8	33.69	11.1	33.47	13.0	33.95	12.1	33.58	--	--
	25	10.8	33.46	11.2	33.58	10.6	33.55	12.5	33.98	11.4	34.10	--	--
	50	10.4	34.46	10.8	33.73	9.7	33.97	9.5	33.87	9.9	34.33	--	--
	100	--	--	10.0	33.84	9.5	33.71	9.0	33.47	8.4	33.96	--	--
July	0	17.2	34.07	16.9	33.17	17.0	33.22	16.4	33.17	17.2	33.61	--	--
	10	16.1	34.80	15.0	32.51	16.2	33.17	16.0	33.19	16.3	33.37	--	--
	25	13.9	33.55	13.7	32.51	14.6	32.58	14.4	32.87	15.8	33.37	--	--
	50	13.4	33.91	13.0	32.50	10.5	32.54	11.0	32.54	10.4	32.26	--	--
	100	--	--	12.0	32.51	10.2	32.51	10.9	33.06	7.9	33.26	--	--
Aug.	0	23.2	--	23.6	33.51	25.7	33.21	24.5	--	24.0	33.49	24.2	33.51
	10	20.5	--	21.3	33.64	21.5	33.46	23.6	--	21.0	33.40	20.0	34.16
	25	19.6	--	20.8	33.33	19.7	33.30	21.5	--	21.3	33.96	16.5	34.25
	50	16.0	--	7.0	33.26	7.5	33.24	7.7	--	9.0	33.98	18.5	34.34
	100	14.6	--	5.8	33.40	5.8	33.30	3.5	--	7.7	33.71	9.7	34.02

Month	Depth (meters)	10 miles		20 miles		50 miles		80 miles		100 miles		150 miles	
		Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity	Temper-ature	Salinity
Sept.	0	22.3	34.53	22.1	33.22	19.5	32.38	13.0	33.03	21.4	32.22	--	--
	10	22.3	33.35	22.0	33.18	19.5	32.38	17.5	32.38	21.4	33.11	--	--
	25	22.1	33.30	20.5	33.35	16.5	32.20	16.5	33.08	17.0	33.80	--	--
	50	21.2	33.34	19.5	33.30	15.4	33.40	15.4	33.08	11.0	33.60	--	--
	100	--	--	19.0	33.37	7.5	32.42	10.4	33.11	9.7	32.43	--	--
Oct.	0	17.8	33.55	19.3	31.79	18.7	33.74	15.3	32.75	15.3	32.62	--	--
	10	18.1	33.58	19.0	33.74	18.5	33.73	14.0	32.75	15.2	32.72	--	--
	25	17.5	33.87	18.5	33.39	18.5	33.58	13.9	32.75	15.2	32.47	--	--
	50	17.5	33.87	18.4	33.66	18.3	33.60	13.4	32.62	14.2	32.87	--	--
	100	--	--	17.9	33.78	17.8	33.74	10.5	32.99	8.6	32.97	--	--
Nov.	0	16.8	34.20	16.8	34.18	15.8	34.15	16.0	34.15	11.5	33.75	13.0	33.22
	10	16.8	34.02	16.7	34.11	15.5	34.16	16.0	34.20	11.5	33.55	12.5	33.26
	25	16.8	34.13	16.5	34.09	15.0	34.11	15.0	34.24	12.0	33.42	12.5	33.21
	50	16.8	34.09	16.5	34.15	14.7	34.09	15.0	34.24	10.5	33.73	9.5	34.07
	100	--	--	16.0	34.16	13.7	34.16	11.0	34.09	6.0	33.64	3.7	33.39
Dec.	0	12.7	33.15	12.5	33.78	10.7	33.78	6.4	33.40	8.2	33.53	--	--
	10	12.4	33.64	12.0	33.75	10.3	33.74	6.2	33.39	7.7	33.51	--	--
	25	12.0	33.78	11.8	33.77	10.6	33.77	6.0	33.38	7.5	33.64	--	--
	50	12.0	33.78	11.6	33.77	9.6	33.50	5.3	33.39	7.5	33.52	--	--
	100	--	--	11.5	33.66	8.4	33.58	4.3	33.41	7.4	33.80	--	--

Note: The numbers of miles show the distance east of the base point at Same.

In March the water temperatures are generally lower than in February. A rather conspicuous low-temperature water zone appears about 50 miles off the coast, while a zone of somewhat warmer water appears in the vicinity of 100 miles off the coast, with low temperatures again at 150 miles off shore.

In April the water temperatures are generally somewhat higher than those of March. However, there is an extremely pronounced zone of cold water at the 80-mile station, and the vertical distribution of water temperatures at this station shows an inverted pattern.

In May the water temperature at the 20-mile station is slightly over 9° C., the temperatures at the 50-mile and 100-mile stations are somewhat lower, while the rise in temperature at the 150-mile station is rather remarkable, with temperatures of 9° to 9.4° C.

In June the tendency toward stratification becomes clear, with water temperatures of 12° to 13.5° C. at the surface, 11° to 13° C. at 10 meters, 10.6° to 12.5° C. at 25 meters, 9.5° to 10.8° C. at 50 meters, and 8.4° to 10° C. at 100 meters. The water temperatures at the 50-mile station are generally lower than those of the other stations.

In July the rise in temperatures in the upper levels is remarkable, the temperatures being about 4° C. higher than those for June. The temperatures from the 50-meter level on down are somewhat lower at stations east of 50 miles off the coast than at the stations nearer to the coast.

In August the surface water temperature continues rising and reaches the maximum for the year at 23.2° to 25.7° C. The zone with the highest water temperatures appears 50 miles off the coast. Within about 100 miles of the coast there is a marked thermocline between the 25-meter level and the 50-meter level, with temperatures at the former of 19.7° to 21.5° C. compared with 7° to 9° C. at the latter. At the 150-mile station the thermocline is deeper, appearing between the 50-meter and the 100-meter levels.

In September the surface water temperatures have already begun to go down with 19° to 22.3° C. indicated at the surface. There are some differences between areas, but in general beyond 50 miles from the coast, the thermocline is between the 50-meter and 100-meter level.

In October the stirring of the sea water by convection is clearly apparent, and water temperatures at all levels above 100 meters show similar values. Water temperatures are highest at the station 20 miles off the coast, and the temperatures are rather conspicuously lower east of the 100-mile station.

In November the water temperatures go down even more with 16.8° C. at the 20-mile station, about 16° C. between 50 and 80 miles off the coast, and a sharp drop farther to the eastward to 11.5° to 12° C.

In December water masses with temperatures above 10° C. are within 50 miles of the coast, and within this area water temperatures gradually drop outward from shore. Water temperatures at the station 80 miles of the coast are much lower, 6° to 7° C., and at the 100-mile station they rise somewhat to over 8° C.

The following table presents some abstracted information for January and August from transverse sectional observations somewhat farther south off Shioyasaki.

If this is compared with the data from the Same section, the temperatures in January are generally higher except for the vicinity of 50 miles off the coast, and the difference becomes more marked the farther eastward one goes until in the vicinity of 150 miles off the coast the temperature is up to 19.5° C. The water mass centered around 50 miles off the coast is colder than the water off Same, showing that the main current of the Oyashio is located in this area.

On the other hand, in August up to 100 miles from shore the temperatures are lower than off Same, and east of 100 miles off the coast there is a zone of remarkably high temperatures. Off Same there was a conspicuous thermocline between the 25-meter and 50-meter levels, but in this sea area there is no particularly outstanding discontinuity apparent down to 100 meters.

Table 77 shows temperature and salinity data for January and August based on sectional observations due east of Inubōsaki near the southern extremity of this sea area.

As the table shows, in January the water temperatures gradually rise the farther one goes off shore, with the maximum water temperatures in the vicinity of the 50-mile station. Farther off the coast from this station the temperatures gradually fall. At the 10-mile station the water temperature at the 100-meter level falls rather steeply, but no direct effect of the Oyashio can be seen at the other stations down to 100 meters.

In August the highest temperature zone is about 50 miles from the coast, showing that this vicinity is about the center of the Kuroshio. From 10 to 20 miles offshore the water temperatures are conspicuously lower than elsewhere, and salinity values are also low in the coastal water zone.

Table 76. --Transverse section line east of Shioyasaki

Month	Depth (meters)	10 miles		20 miles		50 miles		80 miles		100 miles		150 miles	
		Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
Jan.	0	15.2	34.67	11.4	34.09	9.0	33.62	16.9	34.78	19.0	34.87	19.5	35.01
	10	15.2	34.63	11.2	33.86	8.8	33.68	16.4	34.78	19.0	34.92	19.4	35.07
	25	14.9	34.45	11.2	33.78	9.0	33.68	16.2	37.78	18.6	34.88	19.5	34.90
	50	11.8	33.89	11.2	33.86	8.8	33.69	16.0	34.72	18.5	34.79	19.5	34.90
	100	11.0	33.77	11.2	33.77	8.2	33.84	15.2	34.76	15.0	34.29	19.2	34.90
Aug.	0	19.7	--	20.5	33.42	20.2	33.42	23.0	--	24.2	33.48	27.0	34.54
	10	17.0	--	18.2	33.62	19.3	33.60	51.5	--	22.2	33.62	27.0	34.52
	25	16.6	--	14.0	33.96	15.7	33.93	15.6	--	19.5	33.62	25.5	34.67
	50	13.0	--	12.5	33.42	15.2	33.73	15.0	--	18.5	33.57	21.5	34.60
	100	11.5	--	10.8	33.98	9.9	33.95	12.7	--	13.8	33.95	20.5	34.85

Note: (1) From Record of Oceanographic Works for 1937.

(2) The numbers of miles show the distance off the coast.

Table 77. --Sectional observations east of Inubōsaki

Month	Depth (meters)	10 miles		20 miles		50 miles		80 miles		100 miles		150 miles	
		Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
Jan.	0	16.7	34.31	17.2	34.04	19.2	34.58	19.0	34.04	18.0	34.40	18.0	34.76
	10	16.7	34.31	17.2	34.56	20.0	34.52	19.6	34.49	18.8	34.31	18.2	34.85
	25	16.7	34.31	17.2	34.36	20.0	34.51	19.6	34.27	18.8	34.04	18.2	34.85
	50	16.5	34.49	17.2	34.36	20.0	34.25	19.6	34.31	18.8	34.31	18.2	34.58
	100	14.6	33.95	16.8	34.34	19.6	34.31	19.6	34.49	18.7	34.09	18.2	34.85
Aug.	0	19.8	33.28	21.0	34.45	28.3	34.31	27.4	34.51	27.8	34.42	27.2	34.65
	10	17.8	33..68	20.6	34.47	28.1	34.33	27.4	34.56	27.8	34.47	27.2	34.65
	25	14.7	33.80	20.3	34.40	27.0	34.45	26.0	34.63	27.0	34.51	27.0	34.67
	50	14.0	33.80	18.8	34.51	25.2	34.45	24.7	34.67	25.1	34.58	24.0	34.67
	100	13.8	33.82	17.2	33.95	24.0	34.65	19.9	34.76	21.0	34.70	23.5	34.69

Note: (1) From Record of Oceanographic Works for 1937.

(2) The numbers of miles show the distance offshore.

The northern part of this sea area is at the northern limit of the distribution of tunas and spearfishes. Considering the different parts of the area, black tuna are comparatively abundant in the coastal water region, with their fishing grounds stretching to the southern Kurile Islands. Off Kinkazan, spearfishes, principally the striped marlin, are taken, many broadbill are caught everywhere beyond 200 miles from the coast, and at times there are great runs of albacore. The bigeye tuna generally appear to show a trend to greater abundance the farther one gets off shore, but neither they nor the yellowfin have any very important significance. To the northward of the broadbill grounds there are shark fishing grounds, principally for Isurus nasus, and considerable amounts of these fish are taken.

Considered seasonally, the season for black tuna begins in early summer and the fishing grounds gradually shift from the south of the sea area to the north, with catches made until late autumn. Striped marlin are most numerous in midsummer, with some catches until early fall, after which hardly any fish are taken. Broadbill fishing is active from early autumn to early winter with the fishing grounds gradually extending from north to south. About the time broadbill fishing comes to an end, that is around December, large schools of albacore occasionally appear. The shark Isurus nasus is most abundant in April and September, with two fishing seasons during the year.

Of the species mentioned in the foregoing, black tuna in recent years have hardly been taken at all, consequently the fishery for this species has completely died out.

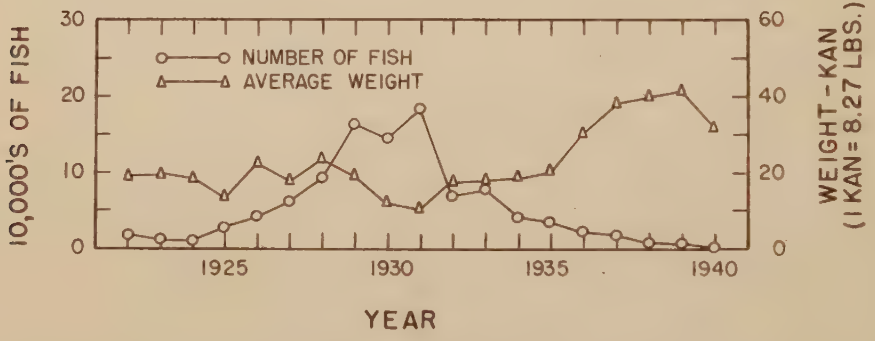

Figure 14.--Annual landings of black tuna at Kushiro

If this graph is compared with a similar curve for Aburatsu (see figure 11), there is agreement in the peaks which appeared in 1931, but the fluctuations in the catch thereafter are very different. At Aburatsu the catch from 1933 to 1939 did not vary greatly, and the fishing situation was shown to be comparatively stable. However, at Kushiro after the peak in 1931 the catch fell off steeply with no recoveries. A conspicuous peak in the catch for 1940 was shown for Aburatsu, but no tendency toward an increase appeared at Kushiro.

A certain degree of agreement can be detected in the average body weight curves in that a trend toward increase from year to year is clearly shown. However, the average weights at Aburatsu were generally about 80 pounds greater than those for Kushiro.

If we consider the relatedness of the fishing conditions and the schools of fish in this sea area and in the waters around Tanegashima, there appear to be at the same time elements which show a relationship between the two areas and elements which deny this relationship. Consequently, with only the data recorded above, it is difficult to either deny or affirm the relatedness of these two sea areas.

As was stated earlier, at about the same time as the fishing season around Tanegashima there are catches of black tuna all over the area around 30° N. latitude. However, one can detect a difference in that the catches around Tanegashima are highly concentrated, whereas those made in other sea areas are extremely scattered. Fairly considerable catches are also made from April to June between Luzon on the south and the Izu Islands, principally within the Kuroshio.

In view of the oceanographic character of this sea area, it appears possible that most of the fish from the various areas mentioned above may concentrate here. Furthermore, because of the conspicuous variations in oceanographic conditions from year to year, a high degree of variability in fishing conditions must also be taken into account. In other words, compared to the schools which congregate around Tanegashima, the fish which gather in this sea area are of many different migratory systems and age groups and the conditions change from year to year. The obvious difference between the average body weight at Aburatsu and at Kushiro, it is thought, can be explained from this point of view, but we do not yet have the data to prove it. In any case, it is a fact that black tuna in Japanese waters showed a peak in the catch curve for their representative fishing grounds in both the south and north in 1931 and thereafter, with some difference in the length of the period, they gradually declined. The phenomenon of a marked increase in the body weight of the fish accompanying this gradual decline in fishing was common to both grounds.

There appear to be various theories with regard to the poor fishing for black tuna in Japanese waters, but the writer thinks that it is probably a natural cyclical fluctuation due to cyclical changes in oceanographic conditions. It is expected, therefore, that there will be a natural recovery, but it is believed that the sort of phenomena described above will have an important significance in establishing policies for this fishery in the future.

Table 78 shows fishing conditions in this sea area based on data from experimental fishing. More data should have been included, as it is thought that quite a large part of the existing data were missed because of difficulty in obtaining them.

The overall catch rate is slightly less than 3.2. First place in the catch is occupied by albacore, which make up about 70 percent of the total. Next in importance are the spearfishes, followed by black tuna and bigeye, with yellowfin appearing only vestigially.

Table 78.--Fishing conditions in the northeastern sea area

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
305	126,841	187	0.15	6	0.01	122	0.10	2,820	2.22	865	0.68

Table 79 provides a comparison of fishing conditions north and south of the line of 40° N. latitude.

Table 79.--Fishing conditions on either side of 40° N.
(northeastern sea area)

Area	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
35°-40° N.	183	91,225	66	0.07	6	0.01	121	0.13	2,817	3.09	737	0.81
north of 40° N.	122	35,616	121	0.34	0	0.00	1	0.00	3	0.01	128	0.36

As the foregoing table shows, fishing is very different north and south of 40° N. The southern part has a markedly lower value for the black tuna catch rate than the northern section, but notably higher catch rates for all the other species. Besides the tunas and spearfishes, there was a catch of 182 sharks in the north and 1,705 sharks in the south. Consequently, the shark catch rate was 0.51 in the northern section and 1.87 in the south.

In the following table this sea area has been split up into five sections of 2° of longitude and the fishing conditions for each have been shown separately.

Table 80.--Fishing conditions by sections (northeastern sea area, 35° to 40° N.)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
140°-142°E.	11	3,052	6	0.20	0	0.02	0	0.00	0	0.00	9	0.29
142°-144°E.	21	8,199	0	0.02	2	0.00	33	0.40	126	1.54	38	0.46
144°-146°E.	19	8,244	15	0.18	0	0.00	7	0.09	244	2.96	27	0.33
146°-148°E.	30	17,084	35	0.21	0	0.00	2	0.01	673	3.94	106	0.62
148°-150°E.	102	54,646	10	0.02	4	0.01	79	0.14	1,774	3.23	557	1.02

Looking at local changes in fishing conditions from east to west without considering the season, one can detect a trend in the foregoing table for the catch rates of both albacore and spearfishes to improve as one goes eastward. However, in the case of the other species, it is difficult to see any trends in the local variations in fishing conditions.

Table 81 shows the fishing conditions by sections in the part of the area north of 40° N. A thorough inquiry is not possible because of the paucity of the data, but it can be seen that black tuna are taken only west of 144° E. The spearfishes appear to show a tendency to increase to the eastward just as they did south of 40° N. The area where the greatest numbers of black tuna are taken is approximately off Erimo Misaki.

In order to see seasonal changes in the fishing conditions, the data have been shown by months in table 82.

Table 81.--Fishing conditions by sections (northeastern sea area north of 40° N.)

Section	Number of stations	Number of hooks	Black tuna Number of fish	Black tuna Catch rate	Bigeye Number of fish	Bigeye Catch rate	Albacore Number of fish	Albacore Catch rate	Spearfishes Number of fish	Spearfishes Catch rate	Total Number of fish	Total Catch rate
140°-142°E.	22	5,358	9	0.17	0	0.00	0	0.00	17	0.32	26	0.49
142°-144°E.	90	24,046	112	0.47	0	0.00	0	0.00	41	0.17	153	0.63
144°-146°E.	3	554	0	0.00	0	0.00	0	0.00	8	1.44	8	1.44
146°-148°E.	--	--	--	--	-	--	-	--	--	--	--	--
148°-150°E.	7	5,658	0	0.00	1	0.02	3	0.05	62	1.10	66	1.17

Table 82.--Fishing conditions by months (northeastern sea area, 35° to 40° N.)

Month	Number of stations	Number of hooks	Black tuna Number of fish	Black tuna Catch rate	Bigeye Number of fish	Bigeye Catch rate	Albacore Number of fish	Albacore Catch rate	Spearfishes Number of fish	Spearfishes Catch rate	Total Number of fish	Total Catch rate
Jan.	23	11,118	20	0.18	7	0.06	151	1.35	81	0.73	259	2.24
Feb.	6	2,010	0	0.00	0	0.00	0	0.00	4	0.20	4	0.20
Mar.	3	1,520	6	0.39	0	0.00	0	0.00	2	0.13	8	0.52
Apr.	6	1,318	0	0.00	7	0.53	2	0.15	3	0.23	12	0.91
July	3	1,044	0	0.00	15	1.44	0	0.00	8	0.70	23	2.20
Sept.	4	1,206	0	0.00	8	0.66	0	0.00	7	0.58	15	1.24
Oct.	11	4,150	0	0.00	0	0.00	0	0.00	63	1.52	63	1.52
Nov.	35	22,509	4	0.02	19	0.08	203	0.91	146	0.64	372	1.65
Dec.	95	57,116	44	0.08	66	0.11	2,463	4.31	432	0.76	3,005	5.26

Although they were omitted from the table, one yellowfin each was taken in July and September and four were taken in December. There are few data for the summer season, but as far as the table shows black tuna are taken only in the winter. Bigeye tuna are most abundant in the summer, with rather high catch rates appearing around July. Albacore show their highest catch rate of 4.3 in December, the main fishing season being from November to January. Spearfishes are scarce from February to April, but considerable numbers are taken in all other months, with the maximum catch rate of slightly over 1.5 appearing in October.

The data from tables 80 and 82 are combined in table 83. From this table it can be seen that the center of the albacore grounds in December is at 146° to 148° E., and that it shifts to 148° to 150° E. in January. In the other months the data are so poorly distributed that a comparison is completely impossible.

With regard to the spearfishes, which follow the albacore in importance in the catch, the following table shows the changes in their fishing by species. The table also includes sharks.

Table 83.--Fishing conditions by months and by sections (northeastern sea area, 35° to 40° N.)

Month	140° - 142° E.			142° - 144° E.			144° - 146° E.			146° - 148° E.			148° - 150° E.		
	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate	Number of stations	Number of hooks	Catch rate
Jan.	-	--	--	1	275	1.82	3	1,307	0.54	9	4,630	1.69	10	4,906	3.44
Feb.	4	1,060	0.38	1	260	0.00	1	690	0.00	-	--	--	--	--	--
Mar.	2	1,260	0.56	1	260	0.38	-	--	--	-	--	--	--	--	--
Apr.	-	--	--	6	1,318	0.91	-	--	--	-	--	--	--	--	--
July	-	--	--	3	1,044	0.20	-	--	--	-	--	--	--	--	--
Sept.	-	--	--	-	--	--	2	486	0.00	2	720	2.22	--	--	--
Oct.	-	--	--	5	1,300	1.08	1	240	0.00	3	1,170	1.62	2	1,440	2.08
Nov.	-	--	--	1	402	0.00	5	2,597	1.12	4	2,910	1.16	25	16,600	1.84
Dec.	5	732	0.55	3	3,340	4.25	5	2,774	4.43	16	8,374	9.16	66	41,896	4.70

Table 84.--Monthly fishing conditions for spearfishes and sharks (northeastern sea area, 35° to 40° N.)

Month	Number of hooks	Striped marlin		Broadbill		Sharks	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	11,118	20	0.18	61	0.55	125	1.12
Feb.	2,060	0	0.00	4	0.20	33	1.64
Mar.	1,520	1	0.01	1	0.01	64	4.21
Apr.	1,318	2	0.15	3	0.23	13	0.99
July	1,044	7	0.67	1	0.10	3	0.29
Sept.	1,206	5	0.40	2	0.16	68	5.64
Oct.	4,150	2	0.05	55	1.32	101	2.43
Nov.	22,509	5	0.02	140	0.62	502	2.23
Dec.	57,116	51	0.09	253	0.46	703	1.23

Considered geographically, the data show a tendency for striped marlin catch rates to be high in the south and low in the north, while the broadbill tends somewhat to be more abundant to the northward. Considered seasonally, striped marlin are most abundant in the summer while the broadbill increase from about October to early winter. No very marked regional differences in the shark catch can be detected, and seasonally they are most abundant in April and September, with rather high catch rates shown for the whole winter season.

Table 85 shows fishing conditions by months in the part of the area north of 40° N.

Of the spearfishes somewhat more than 73 percent are broadbill, the majority of the remainder being recorded as black marlin. The striped marlin and black marlin are taken only in September and October, at which season they make up slightly less than 40 percent of the total spearfish catch. However, data are almost entirely concentrated in the period from September to November, so it is impossible to make any concrete observations on fishing conditions at other seasons.

Table 85.--Fishing conditions by months

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Feb.	1	216	0	0	0	0	0	0	0	0	11	5.10
July	2	720	3	0.41	0	0	0	0	0	0	0	0
Aug.	7	2,220	30	1.35	0	0	0	0	0	0	0	0
Sept.	32	8,532	23	0.27	0	0	0	0	0	0	12	0.14
Oct.	61	18,780	69	0.37	0	0	1	0	3	0.01	74	0.39
Nov.	19	5,148	1	0.02	0	0	0	0	0	0	32	0.62

If we compare the situation north and south of the line of 40° N., it appears that the fishing season in the northern section begins and ends from 1 to 2 months earlier than in the southern section. It can also be seen that the number of species taken in the northern section is less than in the south.

If we compare fishing conditions in general in the northeastern sea area with those in the area east of the Izu Islands adjacent on the south:

1. More black tuna are taken in the northeastern sea area, the peak fishing season for this species is earlier the farther north one goes, and the season is later and longer to the south.

2. Yellowfin are extremely scarce in both sea areas, but they clearly tend to decrease as one goes north.

3. Bigeye tuna are taken with a rather even geographical distribution in the winter season, but they are generally scarce in the summer and decrease as one goes to the northward, hardly any being taken in the extreme northern part of the area.

4. The peak fishing season for albacore is clearly from December to February, and hardly any are taken at other seasons. In both sea areas the catch increases toward the center of the Pacific Ocean.

5. The total catch rate for all species of spearfishes does not differ greatly between the two areas. In general, striped marlin and black marlin are most abundant in the summer season, with broadbill increasing in numbers from October on. Striped marlin and black marlin show a tendency to increase in numbers in early summer in the southern part of the area, with a second increase in the catch rates from late autumn to early winter. In the extreme northern part of the area they increase in numbers from late summer to early fall. These phenomena are considered to show a north-south migration of these species.

6. Sharks are rather abundant in both areas. There are two peak fishing seasons, one in the winter and one in the late summer.

Since this sea area is at the northern limits of the tuna and spearfish longlining grounds, the fishing seasons are more clearly marked than in warmer seas, and there are conspicuous variations in oceanographic conditions from year to year, accompanied by marked fluctuations in fishing conditions.

14. Area of 30° to 35° N., 150° to 180° E.

This sea area is for the most part under the direct influence of the North Pacific Current (the name given to that part of the Kuroshio which leaves Japanese waters and flows eastward), and in the northern part of the area the currents always flow to the eastward. In the southern part of the area a countercurrent branches off from the North Pacific Current and flows approximately southeastward. The subtropical line of convergence, as has already been stated, varies in position with the season, and in the summer it tends to move north, running east and west at about the line of 30° N. latitude. In the winter it moves to the southward. Consequently, it is said that in the summer along the southern border of the sea area great gyrals are formed here and there by the countercurrents branching off to southeastward from the North Pacific Current and currents branching off to the northwestward from the North Equatorial Current.

The vertical distribution of water temperatures and salinities is comparative uniform, the isotherms generally paralleling the parallels of latitude. Around February and March, when the winter water temperatures have reached their minimum, the 16° C. isotherm runs east and west at approximately the northern boundary of this sea area, while the 20° C. isotherm appears at the parallel of 30° N. In summer the surface water temperature over the whole sea area is about 27° C. with 22° to 23° C. at the 50-meter level, and 20° to 21° C. at 100 meters.

This sea area is well known as an albacore ground, and many boats fished there around 1935, but thereafter, as the yellowfin grounds in the equatorial region were developed, the number of vessels operating in this region declined markedly. However, because of the prohibition on fishing in the South Seas after the war, the vessels fishing in these grounds again increased and a rather large catch was produced.

The season is in the winter, with the main fishing season from December to February. Albacore are most numerous in the catch, but considerable numbers of broadbill are taken at the beginning of the fishing season. The catch of other species of tuna is generally almost vestigial, but spearfishes are rather abundant.

As was stated, the fishing season is during the winter and throughout the whole fishing season the west winds blow strongly and continuously, making operations difficult, and shipwrecks are frequent so that although the catch is large it is difficult to characterize this as a superior fishing ground because of the climate.

In the following discussion this area has been divided into three parts of 10° of longitude each, and the fishing conditions within each of these sections are discussed in general.

(a) 150° to 160° E. longitude

The following table summarizes data from past investigations in this section.

Table 86.--Fishing conditions between 150° and 160° E. (30° to 35° N.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
201	165,426	69	0.04	48	0.03	756	0.45	7,932	4.80	864	0.52

The overall total catch rate is slightly over 5.8, with albacore making up slightly under 83 percent of the catch. The catch rates for bigeye tuna and spearfishes are 0.45 and 0.52

respectively. The values for the black tuna and yellowfin catch rates are so low as to be vestigial.

If the section between 150° and 160° E. is divided into five parts by 2° of longitude, and fishing conditions within each of the resulting sections are compared, the results are as shown in the following table.

Table 87. -- Fishing conditions by sections (30° to 35° N., 150° to 160° E.)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
150°-152°E.	53	37,688	55	0.15	5	0.01	106	0.28	962	2.55	228	0.60
152°-154°E.	22	15,147	0	0.00	5	0.03	62	0.41	379	2.50	100	0.66
154°-156°E.	70	42,863	12	0.03	9	0.02	229	0.53	2,509	5.83	320	0.75
156°-158°E.	39	47,061	1	0.00	27	0.06	220	0.47	1,315	2.79	133	0.27
158°-160°E.	21	23,337	1	0.00	3	0.01	143	0.61	1,188	4.09	75	0.32

Black tuna and yellowfin are extremely scarce, so no accurate conclusions can be drawn on the basis of this much data, however, it appears that black tuna tend to be more abundant to the westward, while yellowfin seem to be more abundant in the central portion. Bigeye tuna are taken rather uniformly everywhere, but they are somewhat scarcer at the western extremity and their catch rates appear to be high in the east and low in the west. Albacore are abundant in the area centered around 155° E. and show fairly high catch rates between 158° and 160° E. Spearfishes are abundant west of 156° E. and their catch falls off sharply to the eastward.

The following table shows the fishing situation by months for this sea area as a whole. The data are very unevenly distributed in time and there are only a few data for May and July, while data are completely lacking for the other summer months. Consequently it is impossible to know the changes in the fishing conditions throughout the year, but looking at the table it can be seen that black tuna are not taken from March to November. They are taken sporadically from December to February, and their highest catch rates are found in December. Some yellowfin are taken from the end of October to December, and their highest catch rates appear around October. No very marked changes in the bigeye tuna fishing situation can be detected, but they are more abundant in the winter season from October on with rather high catch rate values for October and December. The albacore increase suddenly after December, and reach their highest catch rate of slightly more than 8.0 in February. They appear to be scarce in the summer, but as they show a catch rate of slightly more than 3.0 in July there appears to be considerable possibility of expecting some catch at times. The spearfishes show their maximum catch rate of slightly under 2.0 in October, and thereafter with the passage of time they tend to decrease gradually.

If these seasonal changes in fishing conditions are compared with the sea area adjacent on the south, a thoroughgoing comparison is impossible because of the lack of data between 25° and 30° N. There is no record of black tuna being taken between 25° and 30° N., and although yellowfin are taken almost throughout the year, the amount is small. The highest bigeye catch rate appears in January, making it appear that there is a lag of about 1 month as compared with the area from 30° to 35° N., but the difference is not very conspicuous. Albacore are most abundant in January, reaching their peak one month earlier than the February maximum appearing in the area of 30° to 35° N. No very marked difference can be detected in the case of the spearfishes. Thus there are notable differences in the case of black tuna and the yellowfin, but no conspicuous differences can be detected for the other species.

Table 88.--Fishing situation by months (30° to 35° N., 150° to 160° E.)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	84	72,949	4	0.01	0	0	340	0.47	4,621	6.33	361	0.50
Feb.	40	25,632	11	0.04	0	0	88	0.34	2,058	8.03	53	0.20
Mar.	6	6,738	0	0	0	0	32	0.47	372	5.82	10	0.15
May	1	300	0	0	0	0	1	0.33	0	0	0	0
July	1	715	0	0	0	0	0	0	22	3.08	2	0.27
Oct.	6	2,462	0	0	3	0.12	14	0.57	1	0.04	48	1.95
Nov.	51	41,245	0	0	32	0.08	112	0.27	348	0.86	343	0.83
Dec.	37	34,159	54	0.16	14	0.04	173	0.51	962	2.82	108	0.31

As we compare this with the sea area east of the Izu Islands, which is adjacent on the west,

1. There appears to be some difference in the black tuna fishing situation as catches are made in the area east of the Izu Islands from January to April, and in this sea area only from December to February.

2. In the sea area east of the Izu Islands yellowfin are most abundant in August and some are taken throughout the year. In this sea area they are taken from October through December. As we have no data for August, it is not possible to make a comparison with the area east of the Izu Islands.

3. There does not seem to be any marked difference between the two sea areas with regard to the bigeye tuna, but in general this sea area appears to have higher catch rates. It should be noted that in the sea area east of the Izu Islands the peak catch rate is reached in April, but no comparison is possible because we lack data for April for this sea area.

4. The peak albacore season appears to be about 1 month later in this sea area.

5. The following table provides a comparison of fishing conditions for spearfishes and sharks in the three sea areas discussed above.

There are remarkably few data for the area from 25° to 30° N., 150° to 160° E., and they are unevenly distributed seasonally so it is difficult to make a comparison. In the case of the striped marlin, the maximum catch rates of the year appear around June and July at 30° to 35° N., 140° to 150° E. (sea area east of the Izu Islands). There are only a few data for July from this sea area, but the striped marlin catch rates are not very high. The maximum catch rates for this sea area appear in October. The broadbill catch rates show high values for October and March in the area east of the Isu Islands, with the maximum in March. In this sea area the maximum catch rate is attained in January. In the area of 25° to 30° N., 150° to 160° E. a rather high value is shown for March. The shark data for various species have been lumped together, so it is not possible to judge the fishing conditions for each species from the table. It can be seen that the catch rate tends to be high around October both in the sea area east of the Izu Islands and at 30° to 35° N., 150° to 160° E.

Table 89.--Comparison of fishing conditions for spearfishes and sharks (25° to 30° N, 150° to 160° E: 30° to 35° N, 140° to 150° E: 30° to 35° N., 150° to 160° E.)

Month	25°-30°N., 150°-160°E.				30°-35°N., 140°-150°E.				30°-35°N., 150°-160°E.			
	Number of hooks	Catch rates			Number of hooks	Catch rates			Number of hooks	Catch rates		
		Striped marlin	Broad-bill	Sharks		Striped marlin	Broad-bill	Sharks		Striped marlin	Broad-bill	Sharks
Jan.	8,931	0.28	0.04	0.44	99,933	0.10	0.51	0.80	72,949	0.06	0.43	0.45
Feb.	13,219	0.42	0.03	0.34	124,661	0.07	0.66	1.10	25,632	0.07	0.13	0.39
Mar.	2,008	0.10	0.45	0.35	49,172	0.10	1.01	1.63	6,738	0.07	0.07	0,06
Apr.	--	--	--	--	9,326	0.04	0.33	0.60	--	--	--	--
May	--	--	--	--	480	0.00	0.00	0.42	300	0.00	0.00	0.00
June	--	--	--	--	184	5.44	0.00	5.44	--	--	--	--
July	--	--	--	--	1,798	2.11	0.00	1.11	715	0.28	0.00	0.14
Aug.	--	--	--	--	1,142	0.61	0.00	2.10	--	--	--	--
Oct.	--	--	--	--	420	0.48	0.71	5.00	2,462	1.90	0.12	4.80
Nov.	--	--	--	--	6,510	0.25	0.26	0.51	41,245	0.56	0.21	0.91
Dec.	2,996	0.93	0.13	0.83	15,840	0.15	0.40	1.39	34,159	0.17	0.14	0.71

Note: (1) The striped marlin column includes some black marlin and sailfish.

In the case of both the tunas and the spearfishes, it appears that fishing conditions in this sea area differ somewhat from those in the sea areas lying adjacent on the west and south. In general the main fishing season for this sea area is in the winter, with striped marlin rather abundant around October, striped marlin and broadbill present in about equal numbers around December, and broadbill predominating thereafter. The albacore, which is the principal element in the catch, increases suddenly after December and reaches the peak of its fishing season in January and February.

(b) 160° to 170° E. longitude

The data for this sea area are summarized in table 90. The overall average catch rate is slightly less than 11.1. As the table shows, the main element in the catch is the albacore, making up 93 percent of the whole. It is followed in importance by the bigeye tuna, and spearfishes are scarce. Black tuna and yellowfin are vestigial.

Table 90.--Fishing conditions at 30° to 35° N., 160° to 170° E.

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
140	175,201	22	0.01	35	0.02	1,062	0.61	17,998	10.27	349	0.20

In table 91 this area has been divided into sections of 2° of longitude and fishing conditions in each of these sections are presented.

Table 91.--Fishing conditions by sections (30° to 35° N., 160° to 170° E.)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
160°-162°E.	34	42,971	12	0.03	4	0.01	176	0.41	6,419	14.91	70	0.16
162°-164°E.	20	21,858	0	0.00	16	0.07	104	0.47	2,542	11.63	24	0.11
164°-166°E.	28	35,377	5	0.01	8	0.02	210	0.59	2,992	8.46	53	0.18
166°-168°E.	28	38,159	3	0.01	5	0.01	278	0.73	2,880	7.55	93	0.24
168°-170°E.	30	36,836	2	0.01	2	0.01	294	0.80	3,165	8.59	109	0.30

On the whole, black tuna and yellowfin are present only vestigially, and do not appear to be centered on any fishing ground. Bigeye catch rates show a clear tendency to be high in the east and low in the west. The albacore show high catch rate values everywhere, but they are particularly high in the west. Spearfish catch rates show some tendency to be higher to the eastward and lower to the westward.

Fishing conditions by months are shown in the following table.

Table 92.--Fishing conditions by months (30° to 35° N., 160° to 170° E.)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	59	68,867	10	0.01	1	0.00	187	0.27	10,380	15.07	71	0.10
Feb.	17	26,447	9	0.03	0	0.00	159	0.60	2,451	9.28	55	0.21
Mar.	3	4,318	0	0.00	0	0.00	42	0.97	44	1.02	18	0.42
Apr.	3	5,511	0	0.00	0	0.00	69	1.25	208	3.77	4	0.07
Aug.	1	500	0	0.00	0	0.00	1	0.20	0	0.00	0	0.00
Oct.	6	2,463	0	0.00	3	0.12	14	0.57	1	0.04	37	1.50
Nov.	9	12,455	0	0.00	13	0.10	124	0.99	525	4.21	66	0.53
Dec.	41	50,875	2	0.00	24	0.05	455	0.89	4,193	8.24	98	0.19

Since data are almost entirely lacking for the summer, changes in the fishing conditions throughout the year are not clear. The table shows only small catches of black tuna in January and February and some yellowfin in November and December. The bigeye catch rate increases twice, once in March and April and once from October to December. The albacore catch rate increases rapidly after November and attains a peak of slightly more than 15.0 in January. The situation in March is not well known because of the paucity of data, but the trend appears to be for a rapid decline in the catch rate in March and somewhat of an increase in

April. However, because of the paucity of data for these two months, we cannot determine whether this sort of change represents a normal condition or whether there is a gradual decline in the catch rates from February through April. Spearfishes are generally scarce, but a catch rate of 1.5 in October shows that there is a possibility of taking certain amounts of them.

If the foregoing is compared with 150° to 160° E.,

(1) The patterns of increase and decrease for black tuna and yellowfin in the two sea areas are almost same.

(2) Bigeye catch rates are generally higher in this sea area, and the seasonal trends of increase and decrease agree well.

(3) Albacore catch rates are generally higher in this sea area, and the peak fishing season is about 1 month earlier.

(4) The spearfish catch rates are generally lower in this sea area, but the seasonal changes in the fishing conditions are in general agreement.

These factors show a very close relationship between the two sea areas.

The most important spearfishes are striped marlin and broadbill, with some black marlin mixed in. The following table shows seasonal changes in the proportions of striped marlin (including black marlin) and broadbill.

Table 93.--Composition of the spearfish catch (30° to 35° N., 160° to 170° E.)

Month	Total Number	Striped marlin		Broadbill	
		Number of fish	Percentage	Number of fish	Percentage
Jan.	71	31	43.7	40	56.3
Feb.	55	24	43.6	31	56.4
March	18	4	22.2	14	77.8
April	4	2	50.0	2	50.0
August	0	0	0	0	0
Oct.	37	35	94.6	2	5.4
Nov.	66	53	80.3	13	19.7
Dec.	98	48	49.0	50	51.0
	349	197	59.9	152	40.1

On the whole striped marlin make up 60 percent and broadbill 40 percent of the total. In October striped marlin are overwhelmingly predominant, but they gradually decline thereafter. On the contrary, the broadbill gradually increase and approximately equal the striped marlin in December, and they are in the majority in March. This is roughly the same situation that was seen in the area of 150° to 160° E. (see table 89).

There are many deficiencies in the data on sharks, so it is not clear what changes take place in the shark fishing.

As the foregoing shows, this sea area is an extremely good albacore fishing ground. The fishing season is completely confined to the winter, with the peak of the season in January. Bigeye tuna are next in importance to albacore, and they are taken most abundantly in November and December. As there are almost no data for the summer, the significance and character of the area as a fishing ground in summer are not yet known, however, judging by a certain amount of data it appears that the area can hardly be considered a very good ground.

(c) 170° to 180° E. longitude

The data from surveys of this area are summarized in table 94.

Table 94.--Fishing conditions from 170° to 180° E. (30° to 35° N.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
202	293,041	28	0.01	6	0.00	1,423	0.49	22,090	7.53	325	0.17

The overall average catch rate is slightly more than 8.0. Albacore are most numerous, making up slightly less than 93 percent of the total catch, followed by bigeye tuna. Spearfishes are scarce with a catch rate of less than 0.2. Black tuna and yellowfin are extremely scarce, almost vestigial, the catch of yellowfin being particularly small. The following table shows fishing conditions within this sea area for sections of 2° of longitude.

Table 95. -- Fishing conditions by 2° sections (30° to 35° N., 170° to 180° E.)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
170°-172°E.	66	94,142	15	0.01	0	0.00	511	0.54	9,715	10.32	90	0.10
172°-174°E.	64	102,783	11	0.01	2	0.00	491	0.48	7,920	7.70	94	0.09
174°-176°E.	23	37,168	2	0.01	3	0.01	148	0.39	2,086	5.61	47	0.12
176°-178°E.	29	40,690	0	0.00	1	0.00	231	0.57	1,689	4.15	76	0.19
178°-180°E.	20	18,285	0	0.00	1	0.00	42	0.23	680	3.72	18	0.10

In a very general way, the table seems to show somewhat of a tendency for black tuna to be more abundant to the westward and scarcer to the eastward. The same tendency was also seen in the area of 160° to 170° E. No differences between sections can be detected in the yellowfin catch. Between 170° and 176° E. the bigeye tuna catch rates are high in the west and low in the east, and the highest catch rate for this species is between 176° and 178° E., with remarkably low values in the extreme eastern part of the area. The albacore show a clear tendency toward higher values in the west and lower values in the east, with a maximum catch rate of 10.32 in the extreme western part. The highest spearfish catch rates are between 176° and 178° E., but in general the local differences in fishing conditions for these fishes are not clear. Table 96 shows fishing conditions by months. There are few data for February, but black tuna have been taken only from November to January. Yellowfin are recorded for May, June, and

December. Bigeye tuna are abundant from January to April, with peaks in their catch rate in January and April and the maximum catch rate for the year in the latter month. The albacore catch rate improves suddenly after November and attains its high of the year, slightly over 9.5, in December. Thereafter it decreases gradually until March, and then the catch rate again improves in April to slightly less than 6.9. These fish are generally scarce in the summertime, but a catch rate of slightly more than 2.0 in June indicates a possibility that there may be good albacore fishing at times. Spearfishes are generally scarce, but they appear to become somewhat more abundant in the summer.

If the foregoing is compared with the area of 160° to 170° E. adjacent on the west,

(1) Black tuna begin to be taken 1 month earlier in this sea area and the season appears to end 1 month earlier.

Table 96.--Fishing condition by months (0° to 30° N., 170° to 180° E.)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	51	73,238	19	0.03	0	0.00	513	0.70	6,492	8.89	114	0.16
Feb.	3	3,899	0	0.00	0	0.00	23	0.60	291	7.05	4	0.10
Mar.	5	9,268	0	0.00	0	0.00	86	0.93	414	4.49	9	0.10
Apr.	3	5,566	0	0.00	0	0.00	56	1.01	382	6.86	12	0.22
May	3	1,500	0	0.00	1	0.06	5	0.33	6	0.40	3	0.20
June	12	1,400	0	0.00	1	0.02	12	0.22	110	2.04	0	0.00
Aug.	7	3,400	0	0.00	0	0.00	5	0.15	1	0.03	2	0.06
Nov.	12	21,010	3	0.01	0	0.00	51	0.24	1,323	6.25	9	0.04
Dec.	106	166,000	6	0.04	5	0.03	750	0.45	15,786	9.51	138	0.08

(2) It is difficult to detect any differences in yellowfin fishing conditions between the two areas, but the catch rates have smaller values in this sea area.

(3) Bigeye tuna are generally less abundant in this area, but the seasonal rise and fall in the catch rate is approximately similar.

(4) The albacore catch rates are also generally lower in this sea area, but the seasonal variations in fishing are generally similar. It appears that these changes tend to take place somewhat earlier in this sea area.

(5) It appears that there is little relation between the monthly changes in spearfish catch rates in the two areas.

For the principal species in the catch, the two sea areas appear to be related, but in general the fishing seasons in this sea area appear to be about 1 month earlier.

It was stated that there appears to be little relationship in the case of the spearfishes. If we look at the monthly composition of the catch, we see that in this sea area throughout the year striped marlin are more abundant than broadbill. In the area between 160° and 170° E., the broadbill increase in numbers in the winter, equaling the striped marlin around December and predominating thereafter. However, in this sea area also there is a clearer tendency for the broadbill to increase in the winter so that the two sea areas are in agreement in this trend.

In many cases the records pertaining to sharks are completely lacking so it is impossible to show the shark fishing situation in terms of catch rates.

15. Area of 35° to 40° N., 150° to 180° E.

This sea area is also for the most part under the direct influence of the North Pacific Current, and the currents flow generally eastward at all seasons of the year.

Since the ocean currents are thus comparatively uniform, there is also little variation in the distribution of water temperatures and salinities and the isotherms generally run parallel to the parallels of latitude.

During the winter, when the water temperatures are at their lowest, the 15° C. isotherm appears along the line of 35° N. and the 10° C. isotherm parallels roughly the line of 40° N. In the summer, when the water temperatures are at their highest, the isotherm of 20° C. runs along the line of 40° N. latitude and the 25° C. isotherm is in the vicinity of 35° N. Since these isotherms reach somewhat higher latitudes at the extreme western side of this sea area than they do to the eastward, they descend from west to east in a very gentle slope.

The extreme western part of this sea area is famous as a broadbill ground, the season being in November and December. In addition to broadbill, striped marlin are abundant, and their fishing season is in September and October. There is a flourishing shark longline fishery which takes principally rakudazame (mōkazame) (Isurus nasus) and the great blue shark. This fishery has two seasons, one in the winter and one in the summer. To the east of the area there are excellent albacore grounds. The albacore fishing season in this sea area is somewhat earlier than that on the grounds to the south and is of shorter duration. Some bigeye tuna are also taken. Hardly any black tuna are taken and yellowfin are also extremely scarce, but depending on the location considerably better catches are sometimes made than are found between 30° and 35° N.

If this sea area is divided into three sections each of 10° of longitude, the general outline of fishing conditions within each section is as follows:

(a) 150° to 160°E. longitude

The following table summarizes the data from surveys carried out in this section.

Table 97.--Fishing conditions at 150° to 160° E.(35° to 40° N.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
309	165,834	12	0.01	111	0.07	638	0.38	2,686	1.62	2,498	1.51

The overall average catch rate is slightly more than 3.5, to which a shark catch rate of 1.8 may be added. The composition of the catch, aside from sharks, is 44 percent albacore, 41 percent spearfishes, and 11 percent bigeye tuna, with yellowfin making up the greater part of the remainder.

If the catch rates given above are compared with those in the area of 30° to 35° N., which adjoins on the south, we find a markedly lower rate for black tuna, a notable increase in yellowfin, somewhat of a drop, although no great difference, in the case of the bigeye tuna, a conspicuous decline in albacore, and a value approximately 3 times greater for spearfishes.

In order to show regional variations in the fishing conditions from east to west this area has been divided into 5 parts of 2° of longitude each. Fishing conditions in each of these sections are shown in table 98. As the table shows, there are more data for the western part than for the eastern part of the area.

Table 98.--Fishing conditions by 2° sections (35° to 40° N., 150° to 160° E.)

Section	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
150°-152°E.	122	53,364	9	0.02	7	0.01	87	0.16	1,333	2.50	870	1.63
152°-154°E.	113	58,005	3	0.01	64	0.11	354	0.61	990	1.70	1,067	1.84
154°-156°E.	45	25,218	0	0.00	13	0.02	107	0.40	97	0.38	335	1.33
156°-158°E.	20	10,164	0	0.00	19	0.19	58	0.57	58	0.57	167	1.64
158°-160°E.	9	4,607	0	0.00	7	0.15	32	0.69	102	2.21	63	1.37

Black tuna were taken only west of 154° E. Yellowfin catch rates are notably lower in the sections of 150° - 152° E. and 154° - 156° E. than they are in the other sections. The distribution of bigeye catch rates resembles that of the yellowfin with a general tendency toward higher rates in the east and lower rates in the west. Albacore are shown to be somewhat more abundant at the eastern and western extremities of the area and scarce in the middle. The spearfishes are generally abundant, with catch rates between 1.3 and 1.8. Comparing localities, there are somewhat higher values west of 154° E. and in the section between 156° and 158° E. In general the most important element in the catch in this sea area is the spearfishes.

Table 99 shows monthly changes in fishing conditions in this sea area.

Table 99.--Fishing conditions by months (35° to 40° N., 150° to 160° E.)

Month	Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Jan.	32	18,720	0	0.00	0	0.00	57	0.30	29	0.15	291	1.55
Sept.	5	1,980	0	0.00	2	0.10	27	1.36	1	0.05	21	1.06
Oct.	53	23,148	0	0.00	50	0.21	203	0.88	110	0.48	546	2.36
Nov.	123	66,958	0	0.00	61	0.09	333	0.35	409	0.61	861	1.29
Dec.	106	61,208	10	0.02	0	0.00	125	0.20	2,147	3.51	779	1.27

The data are limited to the period of 5 months from September to January. The table indicates that black tuna are taken only in November and December. Yellowfin were taken only from September to November, with their highest catch rate in October. Bigeye tuna were taken throughout the whole period covered by the table, but they were most abundant in September and October. There were few data for September, but the maximum catch rate of 1.36 in that month shows the possibility of making fairly large catches of this species. Albacore were very scarce in September, but they gradually increased from October on and reached their highest catch rate of 3.5 in December. The catch rate dropped sharply in January, showing that the fishing season is extremely short. But within the scope of these data the spearfishes maintained a catch rate above 1.0 at all times and attained their maximum catch rate in October.

It is impossible to make a thoroughgoing comparison of these data with those from the area of 30° to 35° N. adjacent on the south because of differences in the seasonal distribution of the data. There appears, however, to be a recognizable tendency for fishing seasons for each species to begin and end about 1 month earlier in this sea area. In addition to this time lag in the fishing seasons, there are considerable differences in the values of the catch rates, but one can recognize many points of agreement in the trends of increase and decline in the catch rates, and it is thought that the populations in the two sea areas have something in common. If this area is further compared with the northern part of the northeastern sea area, which adjoins it on the west, a good agreement in the trends can be recognized just as in the case of the area of 30° to 35° N., 150° tc 160° E.

As was stated earlier, the most important element in the catch in this sea area is the spearfishes. Among these the most important are the striped marlin and the broadbill, with which some black marlin are mixed. Table 100 shows the changes from month to month in fishing conditions for sharks and in the composition of the spearfish catch.

Table 100.--Monthly changes in shark fishing conditions and the composition of the spearfish catch (35° to 40° N., 150° to 160° E.)

Month	Striped marlin		Broadbill		Sharks	
	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Sept.	19	90.5	2	9.5	118	6.00
Oct.	485	88.8	61	11.2	762	3.29
Nov.	435	50.5	426	49.5	1,689	2.52
Dec.	42	5.3	737	94.7	1,200	1.96
Jan.	4	1.4	273	98.6	422	2.25

Data for the summer are completely lacking, so the situation is not well known, but around September striped marlin (including a small number of black marlin and sailfish) are overwhelmingly in the majority, with broadbill appearing to be less than 10 percent of the total. In October the proportion of broadbill is increased somewhat over September, but striped marlin are still overwhelmingly predominant and make up 88.8 percent of the total spearfish catch. In November the proportion of broadbill increases sharply and striped marlin and broadbill appear to be taken in approximately the same proportions. From December to January the situation is exactly the opposite of that which obtained in September and October, with broadbill swordfish overwhelmingly in the majority. In January, particularly, the striped marlin catch becomes very small and indeed almost vestigial. We have no data from February on so we do not know what further changes take place.

The maximum catch rate for sharks appears in September, after which the catch rate gradually declines until December. They show a slight tendency to increase in January.

If this is compared with the area of 30° to 35° N., 150° to 160° E., where the month in which the proportions of striped marlin and broadbill in the catch became approximately equal was December, this sea area is about 1 month later. Compared with the northeastern sea area, which is adjacent on the west, and in which the two species attained approximately equal proportions around September, there is quite a conspicuous time lag. In the northeastern sea area the proportion of striped marlin was quite high even in January. The changes from month to month in these three areas are summarized in table 101.

Table 101.--Comparison of the percentage composition of the spearfish catch (35° to 40° N., 150° to 160° E.; 30° to 35° N., 150° to 160° E.; northeastern sea area)

Month	35°-40°N., 140°-150° E.			35°-10°N., 150°-160°E.			30°-35°N., 150°-160° E.		
	Number of fish	Striped marlin	Broad-bill	Number of fish	Striped marlin	Broad-bill	Number of fish	Striped marlin	Broad-bill
Jan.	74	17.6	82.4	277	1.4	98.6	361	12.7	87.3
Feb.	4	0.0	100.0	-	-	-	53	35.8	64.2
Mar.	2	50.0	50.0	-	-	-	10	50.0	50.0
Apr.	5	40.0	60.0	-	-	-	-	-	-
May	-	-	-	-	-	-	0	-	-
July	8	87.5	12.5	-	-	-	2	100.0	0.0
Sept.	5	60.0	40.0	21	90.5	9.5	-	-	-
Oct.	7	28.6	72.4	546	88.8	11.2	48	93.5	6.5
Nov.	145	3.4	96.6	861	50.5	49.5	319	72.7	27.3
Dec.	314	16.2	83.8	779	5.3	94.7	108	55.5	44.5

In addition to these seasonal changes, the changes in the composition of the spearfish catch at different latitudes are also remarkable. These fluctuations are shown in table 102. This table shows that from October on the striped marlin rapidly move from north to south and the broadbill then moves south as if following them.

Table 102.--Percentage composition of the spearfish catch by month and by latitude (35° to 40° N., 150° to 160° E.)

Month	35° - 36° N.		36° - 37° N.		37° - 38° N.		38° - 39° N.		39° - 40° N.	
	Striped marlin	Broad-bill	Striped marlin	Broad-bill	Striped marlin	Broad-bill	Striped marlin	Broad-bill	Striped marlin	Broad-bill
Sept.	-	-	-	-	-	-	90.5	9.5	-	-
Oct.	93.2	6.8	87.5	12.5	88.4	11.6	79.7	20.3	-	-
Nov.	78.2	21.8	81.3	18.7	59.9	40.1	34.0	66.0	2.1	97.9
Dec.	7.2	92.8	6.6	93.4	8.1	91.9	2.3	97.7	1.3	98.7
Jan.	1.5	98.5	0.0	100.0	0.0	100.0	-	-	-	-

As the foregoing shows, the principal elements in the catch in this sea area are the spearfishes, led by the striped marlin and the broadbill, and the albacore. The *rakudazame* (*Isurus nasus*) also has considerable significance in the catch. Some bigeye tuna are also taken, but the other tunas have hardly any significance as an object of the fishery. The fishing season is about half the year from September to January. At the beginning of the season striped marlin are abundant and there are also many sharks taken. With the passage of time the broadbill swordfish catch increases, and from December on this species is the principal item in the catch. In December the albacore catch also increases, and considerable numbers of these fish are taken.

(b) 160° to 170° E. longitude

The data from investigations in this section are summarized in table 103.

Table 103.--Fishing conditions from 160° to 170° E.
(35° to 40° N.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
90	108,803	2	0.00	12	0.01	597	0.55	12,637	11.62	191	0.18

The overall average catch rate is quite high, being slightly less than 12.4. The most important element in the catch is the albacore, which makes up more than 94 percent of the total catch. Next most important is the bigeye tuna, which is 4.4 percent of the total catch. Spearfishes are extremely scarce, their catch rate being less than 0.2. Black tuna and yellowfin are almost entirely without significance as objectives of the fishery.

If this is compared with the above-described section between 150° and 160° E., which adjoins this section on the west, there is a rather conspicuous decline in the black tuna and yellowfin, and something of an increase in the catch rates of bigeye tuna. The increase in the albacore catch rate is extremely conspicuous, the catch rate in this sea area being 7 times that in the area described above. The spearfish catch rate has decreased sharply, being only one-ninth what it was in the previously described sea area.

Comparing this area with the section 30° to 35° N., 160° to 170° E. which adjoins it on the south, black tuna and yellowfin are rather conspicuously scarcer in this sea area, but otherwise, although there are some differences in the catch rates, the composition of the catch is very similar, showing that this area is more closely related to the area to its south than to the section to the west.

If we look at these phenomena without taking into consideration the factors to be discussed below, it appears that in the sea areas north of 30° N. latitude the distribution of the tunas and spearfishes which are taken by the tuna longline fishery does not differ greatly with latitude, that is from north to south, but varies mostly with longitude, that is from east to west, with a distributional boundary in the vicinity of 160° E. Of course this does not mean that the pattern of distribution in a north-south direction is completely identical throughout the year. One can detect marked seasonal changes from north to south, but these are mainly time lags and do not have the character of complete differences between regions in the composition of the catch at the same season.

The first cause of marked differences in the composition of the catch at different longitudes is differences in oceanographic conditions. In the sea areas adjacent to Japan the influences of the Kuroshio and the Oyashio work strongly, and the effects of the Kuroshio extend much farther north than they do to the eastward in the central part of the Pacific. The Oyashio extends here and there in wedges into this current. To the eastward the oceanographic conditions are generally uniform, with the isotherms lying approximately along the parallels of longitude. It goes without saying that this situation has a great effect on the distribution of the fishes discussed above. However, as the discussion of the distribution of these fishes has been based upon the catch rates of the longline fishery, we must take account not only of these differences in the oceanographic conditions but also of differences in the construction of the fishing gear and the bait that is used.

We can see certain local differences in the construction of the fishing gear. On the distant grounds off to the east lines especially designed to take albacore have been much used in the past, and the data which we have handled here are mainly derived from this type of line. These longlines usually have a large number of short branch lines. Here and there they have long branch lines called "burakuri", which are said to be intended to catch bigeye tuna. Longlines of this construction are not used on the fishing grounds of the northeastern area, where spearfishes and tuna other than the albacore are the objective of the fishery. Consequently, room is naturally left for further examination of the appropriateness of discussing the distribution of species and the characteristics of fishing grounds on the basis of the catch rates, as was done in the foregoing. There will doubtless be opportunity for further discussion of this problem in later chapters.

Table 104.--Fishing conditions by sections (35° - 40° N., 160° - 170° E.)

Section	Number of stations	Number of hooks	Bigeye		Albacore		Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
160°-162°E.	2	2,582	4	0.15	299	11.67	0	0.00	3	0.12	19	0.74
162°-164°E.	24	26,617	166	0.62	3,468	13.03	17	0.06	8	0.03	143	0.53
164°-166°E.	16	16,989	35	0.21	3,889	22.90	23	0.14	5	0.13	103	0.61
166°-168°E.	19	25,594	173	0.68	2,420	9.50	32	0.12	33	0.13	100	0.39
168°-170°E.	29	37,021	219	0.59	2,561	6.89	33	0.09	37	0.10	79	0.21

In table 104 this sea area has been divided into five parts of 2° of longitude each, and fishing conditions within each of these sections are presented separately. From the table we can see that catch rates for bigeye tuna are low in the extreme western portion and in the center, with fairly high catch rates everywhere else. Albacore catch rates in the central portion are extremely high but tend to decline gradually to the westward. To the eastward they fall off sharply. Differences between localities in the fishing conditions for the spearfishes are not conspicuous. Sharks, on the whole, like the spearfishes are much less abundant than in the area from 150° to 160° E. As for localized differences, there is clearly a trend for the catch rates to be high in the west and low in the east.

If we compare this area with the area of 30° - 35° N., which adjoins it on the south, it is difficult to find any common trends for the principal items in the catch, which are bigeye tuna, albacore, and spearfishes.

The data are almost confined to the two months of November and December, so seasonal changes in fishing conditions are not clear, however, the data have been assembled in table 105 so as to show changes in fishing conditions from month to month.

For all species other than albacore the November catch rate values are higher than those for December. Albacore in December have an extraordinarily high catch rate of slightly more than 16.8. The situation in January is not clear because of the paucity of data, but the possibility of rather large catches is indicated. The data for February are also extremely poor, but they too appear to indicate the possibility of fairly high catch rates.

Table 105.--Fishing conditions by months (35° to 40° N., 160° to 170° E.)

Month	Number of stations	Number of hooks	Bigeye		Albacore		Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Nov.	37	47,942	289	0.60	2,750	5.74	76	0.16	40	0.08	254	0.53
Dec.	49	57,332	319	0.56	9,708	16.83	22	0.04	39	0.07	181	0.32
Jan.	1	1,200	0	0.00	232	11.00	1	0.08	0	0.00	1	0.08
Feb.	1	828	0	0.00	65	7.85	0	0.00	0	0.00	0	0.00
June	1	400	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Aug.	1	400	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

If the foregoing is compared with the area from 150° to 160° E. which adjoins it on the west, rather conspicuous differences in the values of the catch rates can be detected, but the trends of increase and decrease are in good agreement for all species. If the area is further compared with the area of 30° to 35° N., 160° to 170° E. adjacent on the south, it can be seen that the trends of increase and decrease of the catch rates for bigeye tuna and spearfishes are in general agreement, however, there is clearly a lag in the peak of the albacore fishing season, the maximum catch rate at 30° to 35° N. appearing in January with a numerical value of 15.0.

If we compare the proportions of striped marlin and broadbill, at 35° to 40° N., 150° to 160° E. broadbill are about 60 percent of all the spearfishes. However, in this sea area the proportions are reversed and striped marlin are about 55 percent of the spearfish catch. As was stated earlier, in the northern areas in general the striped marlin increase markedly around September and October, then from November on they decrease rapidly and there is a conspicuous increase in broadbill. The data for this sea area are, as shown in table 105, almost entirely confined to November and December. Nevertheless, it is worthy of note that broadbill are scarce in comparison with striped marlin. It is considered that this sort of phenomenon is controlled by the distribution and migrations of the broadbill, and the two sea areas are adjudged to differ somewhat in their character as fishing grounds.

(c) 170° to 180° E. longitude

The data for this section are summarized in table 106.

Table 106.--Fishing conditions at 170° to 180° E. (35° to 40° N.)

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
108	157,354	12	0.01	1	0.00	754	0.48	13,182	8.38	176	0.11

The overall catch rate for tunas and spearfishes is slightly less than 9.0, a rather high figure. The most abundant item in the catch is the albacore, which makes up slightly more than 93 percent of the catch excluding miscellaneous fish. It is followed in abundance by the broadbill with slightly more than 5 percent. Spearfishes are scarce making up only slightly more than 1 percent. Black tuna and yellowfin are extremely scarce, and have almost entirely lost their significance in the catch.

If this is compared with the area from 160° to 170° E. which lies adjacent on the west, there is a slight increase in black tuna and a sharp decline in yellowfin. There appears to be somewhat of a tendency to decrease in the case of bigeye tuna, but there is no great difference, the spearfish catch rate has dropped by half, and the albacore catch rate is rather conspicuously lower. Compared with the area of 30° to 35° N. adjacent on the south, both black tuna and yellowfin are extremely scarce, but the bigeye catch rates show quite equal values. The albacore catch rate is somewhat higher in this sea area, but the difference is not as marked as that between this sea area and the area to the west of it. Spearfishes are scarce in both sea areas, but the decline is somewhat more conspicuous in this area.

The following table shows fishing conditions within the area by sections of 2° of longitude.

Table 107.--Fishing conditions by sections (35° to 40° N., 170° to 180° E.)

Section	Number of stations	Number of hooks	Bigeye		Albacore		Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
170°-172°E.	44	61,603	386	0.63	5,849	9.49	53	0.08	45	0.07	300	0.50
172°-174°E.	35	44,316	168	0.38	4,701	10.61	26	0.06	16	0.04	219	0.49
174°-176°E.	20	14,660	62	0.42	1,243	8.48	14	0.09	8	0.05	38	0.26
176°-178°E.	17	24,640	156	0.64	1,395	5.68	9	0.04	4	0.02	120	0.49
178°-180°E.	--	--	--	--	--	--	--	--	--	--	--	--

The bigeye catch rates are somewhat lower in the central section, and higher at the eastern and western extremities. In general albacore catch rates are high in the west and low in the east, with a maximum catch rate of 10.6 in the section from 172° to 174° E. The spearfish catch is so small as to be of no great importance, but although it is difficult to perceive any local differences in fishing conditions for striped marlin, the broadbill appear generally to have higher catch rates in the west and lower in the east. A remarkably low catch rate for sharks in the section from 174° to 176° E. is indicated, but elsewhere they generally show uniform values.

When these conditions are compared with those in the area of 30° to 35° N., 170° to 180° E., a very similar trend for bigeye tuna is indicated. In general albacore catch rates are higher in this sea area, but in both areas roughly the same trend of higher rates in the west and lower rates in the east can be detected. It is difficult to recognize any marked fluctuations in the case of spearfishes and sharks. These facts indicate that the two sea areas have the same characteristics as fishing grounds.

The local variations in fishing conditions from north to south have been shown in table 108 by dividing the area into sections of 1° of latitude.

From the table it is clear that the bigeye catch rates are high in the south and gradually decrease toward the northward. In the case of the albacore, on the contrary, the trend is for high rates in the north and lower in the south, but this trend is not as regular as in the case of the bigeye. For the spearfishes no definite trend can be detected, but the sharks clearly show higher rates in the south and lower rates in the north, just as do the bigeye tuna.

Table 108.--Fishing conditions by latitude (35° to 40° N., 170° to 180° E.)

Section	Number of stations	Number of hooks	Bigeye		Albacore		Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
35°-36°N.	72	87,028	539	0.62	7,568	8.80	69	0.08	52	0.06	472	0.54
36°-37°N.	22	28,357	137	0.48	2,154	7.60	15	0.05	5	0.02	115	0.41
37°-38°N.	11	13,885	52	0.37	1,400	10.08	9	0.06	6	0.04	52	0.37
38°-39°N.	10	12,760	37	0.29	1,422	11.14	8	0.06	9	0.07	36	0.29
39°-40°N.	3	4,289	2	0.05	454	10.71	5	0.12	1	0.02	12	0.28

Table 109 shows changes in fishing conditions from month to month.

Table 109.--Fishing conditions by months (35° to 40° N., 170° to 180° E.)

Month	Number of stations	Number of hooks	Bigeye		Albacore		Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Oct.	3	5,335	14	0.26	168	3.15	8	0.15	0	0.00	42	0.75
Nov.	52	78,702	316	0.40	5,677	7.22	50	0.06	28	0.04	441	0.56
Dec.	49	69,264	420	0.61	6,577	9.50	42	0.06	46	0.06	223	0.32
Jan.	3	3,753	4	0.11	760	22.92	1	0.03	1	0.03	0	0.00
June	1	300	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

The data are almost entirely concentrated in November and December, so it is difficult to show clearly the changes in fishing conditions from month to month. Judging from what is shown in the table, the bigeye gradually increase from October to December, reaching their maximum catch rate in the latter month. Like the bigeye, the albacore also increase with the passage of time from October on and attain a catch rate of 9.5 in December. In January the catch rate is slightly under 23, but because there are so few data it is not clear whether or not the rate is always that high, however, it may be considered that there is a possibility of a fairly high catch rate. The striped marlin tend to decrease gradually from October on, while the broadbill appear to increase somewhat in December. The shark catch rate shows a tendency to decrease gradually after October.

It can be seen that the conditions described above coincide perfectly with those in the area of 35° to 40° N., 160° to 170° E., which lies adjacent on the west. Only in the case of the albacore in January is there a marked difference, but this is considered to be due to the paucity of the data. It also appears that conditions here are in general agreement with the situation in the area of 30° to 35° N., 170° to 180° E., which lies adjacent to this area on the south.

Taking a general view of the whole area of 35° to 40° N., 150° to 180° E., it is, as has already been stated, an extraordinarily good albacore ground. The fishing season is from October to January, with the peak in December. The albacore are distributed all over this sea area, but there is some difference in fishing conditions from east to west so the distributional pattern is thought to differ. Not only is a difference in the density of distribution detectable, but there appear also to be local differences in the size of the fish that are taken, and on the basis of these differences Uda has reported the existence of three groups of fish. Differences from north to south in fishing conditions appear mainly to accompany the seasons, and there seems to be a tendency for the fishing season to be somewhat earlier in the north and later in the south.

The species next to the albacore in importance is the bigeye tuna. Bigeye catch rates are shown to be higher in the south and to gradually decrease to the northward. No very marked differences in fishing conditions can be detected in an east-west direction, although there appears to be some tendency for catch rates to be higher in the east and lower in the west. The fishing season is from October to December, with the peak of the season in the latter month.

Spearfishes are generally scarce, most of them being striped marlin and broadbill. Striped marlin catch rates are highest around October, after which they gradually decline to December and then drop off sharply in January. The situation in the summer is unknown because data are completely lacking. Broadbill swordfish gradually increase from October on and attain their highest catch rate around December. Considered geographically, both the striped marlin and the broadbill show a tendency to be most abundant in the extreme western part of this sea area and to decrease as one goes eastward. This tendency appears particularly conspicuous in the case of the broadbill. In a north-south direction, striped marlin are more abundant in the south and broadbill in the north. Black tuna and yellowfin are almost entirely without significance in the catch. Shark catch rates tend to be high in the west and low in the east, and if considered in terms of latitude, they appear to be generally high in the south and low in the north, but because many of the data are deficient, there appears to be need for further analysis of the catch rates given in the foregoing tables.

16. Area of 40° to 43° N., 150° to 155° E.

This sea area is located at the extremity of the tuna longline fishing grounds, so the season is short and the species in the catch are limited.

There are few data from investigations in this area, and table 110 summarizes them.

Table 110.--Fishing conditions at 40° to 43° N.,
150° to 155° E.

Number of stations	Number of hooks	Black tuna		Yellowfin		Bigeye		Albacore		Spearfishes	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
23	19,167	0	0.00	0	0.00	2	0.01	4	0.02	135	0.07

The overall average catch rate for tuna and spearfishes is only 0.8. As the table shows, there are no records at all of captures of black tuna or yellowfin. Catches of bigeye tuna and albacore are almost vestigial, and the spearfishes are the main part of the catch. Some sharks are also taken, indeed, shark fishing is, as will be related below, rather active.

Data exist only for the months of October and November, and the following table gives a comparison of fishing conditions in these two months.

Table 111.--Fishing conditions by months (40° to 43° N., 150° to 155° E.)

Month	Number of stations	Number of hooks	Striped marlin		Broadbill		Sharks	
			Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
Oct.	15	14,391	1	0.01	124	0.86	187	1.30
Nov.	8	4,776	1	0.01	11	0.23	444	9.30

They have been omitted from the table, but bigeye tuna and albacore were only taken in October. Among the spearfishes, striped marlin were extremely scarce in both months and were quite vestigial, but broadbill were rather numerous and had a fairly high catch rate in October. However, they seem to have declined sharply in November. The sharks on the contrary showed a marked increase in their catch rate to 9.3 in November.

If this is compared with the area of 40° to 43° N., 140° to 150° E., which lies adjacent on the west, there was a considerable number of black tuna taken in October with a catch rate of 0.37 in the area of 140° to 150° E. However, in this sea area none of these fish were taken at all. Few bigeye and albacore were taken in either area, and these species appear to have almost no significance in the catch. Of the spearfishes, in October in the area of 140° to 150° E. the striped marlin (including black marlin and white marlin) had a catch rate of 0.13 and made up 30 percent of the total spearfish catch. In November they declined sharply, the catch rate was only 0.02, and they made up only 3 percent of the spearfish catch. However, in this sea area the proportion of striped marlin in the catch is very small in both October and November. These phenomena probably mean that the two sea areas have a quite different character as fishing grounds. Comparing this area with the area of 35° to 40° N., 150° to 160° E., which adjoins it on the south, in both October and November the catch of yellowfin, bigeye, and albacore in the latter area is much greater than in this area, as is the catch of spearfishes. As for the proportion of striped marlin and broadbill, in this sea area broadbill make up almost all of the catch in both months, while in the area of 35° to 40° N., 150° to 160° E. in October the striped marlin are slightly under 89 percent of all spearfishes and in December they are still more than 50 percent.

From the foregoing it is thought that this sea area differs somewhat in its character as a fishing ground from the sea areas surrounding it. In effect, this sea area is outside the range of distribution of most of the tunas and spearfishes or is at their extreme northern limit, and therefore only a vestigial distribution is indicated or the fish do not occur at all. Fishing seasons, as far as existing data show, are extremely short and the important species in the catch are limited to the broadbill and sharks.

VI. The Distribution of the Tunas and Spearfishes as Shown by Their Catch Rates

The preceding chapters have presented a discussion of the significance and characteristics of various sea regions as fishing grounds, based on data gathered by research vessels in the past. Thus the general outline of the distribution and seasonal changes in catch rates for tunas and spearfishes has already been set forth. The present chapter is an attempt to bring together and summarize the various facts concerning the distribution of tunas and spearfishes in the western Pacific Ocean.

The first question is what are we going to use as a criterion for determining the presence or absence of these fishes? It is, of course, impossible to observe their occurrence directly as in the case of land animals and plants. Consequently their presence can only be discussed in terms of the fish catch. Furthermore, the only suitable method which can be thought of for considering the density of their distribution is based on the fishing conditions.

Hitherto tuna fishing conditions have been expressed in terms of the catch per voyage or the catch within a certain area within a definite period, however, these modes of expression have the defect that fishing effort is not accurately expressed. In order to correct this defect, I have, as previously set forth, taken the catch per hundred hooks fished, called it the catch rate, and used it to show fishing conditions.

In the case of the skipjack live bait fishery, the so-called " biting qualities" of the schools greatly influence the fishing conditions, and even though the catch rate is calculated on the basis of the number of poles fished, it cannot be said to be always necessarily correlated with the density of distribution.

It is of course conceivable that we have the factor of biting qualities in the tunas and spearfishes too, but in the case of the longline fishery we can think of absolutely no means for evaluating this factor. This means that there are no grounds on which to refute the hypothesis that the catch rate is always in proportion to the density of occurrence of the fishes. In other words, at present we can think of no other method than to assume that the catch rate is proportional to the density of distribution of the fish.

Now if we do make this assumption, the chief problems which arise are differences in the construction of the fishing gear, differences in the bait used, errors arising from differences in the number of times fished and the number of units of gear employed, and fluctuations in the fishing conditions from year to year.

If all of our data represented the use of identical fishing gear, there would be no problem at all, however, the fishing gear has changed with the passage of time, different research vessels sometimes used different types of gear, and gear of differing design is used depending upon the fishing ground and the type of fish sought.

The effect of fishing gear construction on the catch rate has as yet not been sufficiently studied, but there are data which indicate that it is not to be taken lightly. For example, the data collected by the Hakuyō Maru in various southern areas show, as may be seen in the following table, that differences in the length of the branch lines greatly influence the catch rate.

Table 112.--Fishing results with branch lines of different lengths (Hakuyō Maru)

Year	Date	Area	Short Branches		Long Branches		Notes
			Fish	Percentage	Fish	Percentage	
1930	5 Nov.	Nicobar Is.	28	27	76	73	Fish were especially numerous on the long branches on four occasions and on the short branches on three occasions.
1931	6 Jan.	Sumatra-Java	32	29	81	71	
1933	8 Jan.	New Guinea-Solomon Is.	13	23	43	77	Fish were particularly numerous on the long branches on two occasions and on the short branches on one occasion. No record was made on ten occasions

"Percentage" does not represent the catch rate but the proportion of the fish caught which were taken on long and short branches.

The long branches were 99 feet long and there were two of them per basket of gear. The short branches were 30 feet long and there were four per basket. There was one 90-foot float line to each basket.

Table 112 shows that even in three different regions there was little variation in the proportions of fish taken by the two kinds of branch lines. Since there were twice as many short branches as long branches, the catch rate of the long branches was 5 to 6 times that of the short branches. There are almost no such data for Japanese waters, but a certain amount of similar data was gathered in southern waters by the Shōnan Maru and other research vessels. These data show a rather clear tendency for the catch rates for the tunas to be greater the deeper one goes, at least down to 100 meters, for the spearfish catch rates to be greatest at 50 to 60 meters and for the shark catch rates to be greatest at shallow levels.

Most of the gear used by research vessels in exploratory fishing falls into three general categories. As a matter of fact, however, in many cases there are inadequate records of the gear that was used and for much of the data we do not know what type of gear was employed. Of the three types of gear, one is the albacore line, and the other is a line specially designed to catch spearfishes and sharks. The third type is that generally used to catch tunas and spearfishes. However, although we may say there are three types, it is not a matter of each type having a completely different construction, but simply that they differ with regard to the number and length of branch lines, the length of float lines, the shape of the hooks, and so forth.

On the albacore lines employed in the past, the branch lines were short and numerous. The number of branch lines was not standardized but ranged from 10 to 20 or 30 per basket. For the most part, about two long branch lines, called "burakuri", were hung among the short branches. The short branches were mainly intended to take albacore, while the burakuri were for catching bigeye tuna or other tunas and spearfishes. In the longlines designed to take sharks and spearfishes, the branch lines were short and most such gear had about nine branches per basket. The third type of gear, that commonly employed, has four to six branch lines per basket, the length of which is generally greater than those of the other two types of line.

From the geographical and seasonal point of view, we may say in a very general way that in the winter in waters north of 25° N. latitude, the gear used was almost entirely albacore line. To the south of this latitude, ordinary longlines are used throughout the year. The use of spearfish and shark longlines is comparatively localized, such gear being found in Formosan waters, west of Kyūshū, and in the waters of northeastern Honshū and Hokkaidō. The gear formerly used around Tanegashima to take black tuna was of a peculiar design.

Except for the slight amount of data presented above, almost nothing is known at the present time with regard to the question of what effect the length of the branch lines, or in other words, the depth at which the hooks hang, has on the catch rate for the various species. It is said that bigeye tuna are more often caught on long branch lines, or that spearfishes are more often caught in the shallow levels and so forth, but hardly any scientific demonstration of these facts has been made. Taking albacore lines as an example, black tuna, yellowfin, bigeye tuna, spearfishes, and sharks are all caught on this gear. If all species other than albacore were caught on the so-called burakuri and if the albacore were always taken on the short branch lines, the catch rate by species could be accurately calculated. However, as a matter of fact, all species are taken both on the short lines and on the burakuri. Consequently, in calculating the catch rates, the total number of branch lines, or in other words the number of hooks employed, must be used.

As was said earlier, it is thought that the effect of fishing gear construction on catch rates is not to be regarded lightly, and it is naturally to be considered that some correction for differences in gear construction is necessary in comparing catch rates for each species.

However, this correction is a problem which cannot be solved until future research has shown the effect which branch line length has on the catch rates for each species at different seasons and in different areas. Here we must, perforce, ignore the differences in construction of the fishing gear, and assume that it all has equal catching power, just as we earlier assumed that the catch rate is proportional to the density of occurrence of the fish, and on the basis of these two assumptions, we will examine the distribution of each species.

A. Black Tuna

Stated very roughly, the distribution of the black tuna extends all over the northwestern Pacific Ocean and the northeastern part of the South China Sea between 15° and 41° N. latitude and east of 120° E. longitude. Thus its range, if we except the South China Sea and the waters around the Ogasawaras, is definitely restricted to the Kuroshio and the North Pacific Current.

The waters with a high density of occurrence, that is to say waters with high catch rates, are extraordinarily limited. Citing them from south to north, they are the coastal waters east and west of Luzon, the waters off the Miyako chain and Okinawa, the waters around Tanegashima, and the northern part of the Northeastern Sea Area. They occur very widely between 30° and 35° N. latitude, and to the east of the meridian of 140° E. longitude, but the catch rates in this area are very low and fish are taken only sporadically.

The season on the fishing grounds off the east and west coasts of Luzon and near Formosa, although it may be slightly earlier or later from year to year, begins in March and ends in early June. In some years the first catches are made in the latter part of February, but fishing gradually becomes better from the latter part of March on. There are few data on the catch rates and the seasonal changes are not clear. The following table presents data for the period from March to May.

Table 113.--Black tuna fishing conditions in Luzon waters

Position	Date	Number of stations	Number of hooks	Number of fish	Catch rate
17° - 18° N. 120° -121° E.	Mar. 15-24, 1935	5	900	57	6.33
19° - 20° N. 120° -121° E.	May 10-21, 1935	6	960	43	4.48
18° - 19° N. 120° -121° E.	May 8-22, 1935	10	2,200	77	3.50
18° - 20° N. 122° -124° E.	May 5-14, 1939	10	2,400	68	2.83

Note: Data from vessels reporting to the Formosa Government-General. As this table shows, the catch rates were surprisingly high, indicating great density of occurrence.

The season in the Miyako Islands and Okinawa is chiefly in May and June, somewhat later than in the Luzon area; however, catches have been reported in April. Catch rates range from a low of 0.23 to a high of 9.37, with remarkably high catch rates being recorded from time to time. The catch rates of 9.37 and 3.76 were each recorded for only one trial and therefore should probably be interpreted only as meaning that there is a possibility of such catch rates occurring.

Turning next to the northward to the waters around Tanegashima, the peak fishing season is from December to February, catches continuing to be made into March, with fairly high catch rates being indicated in some years even in April. Farther to the east in the waters extending to 145° E. longitude and including the Ogasawara area, catches are made from April to June, but on the whole they are extremely scattered and the catch rates show very low values.

Considerable fish are taken in June and July off the Tokiwa region of eastern Honshū. Densely congregated schools again appear from the Sanriku region of northeastern Honshū to the south coast of Hokkaido and fish are taken continuously from July to November.

In the area east of 140° E. longitude and centering between 30° and 35° N. latitude some black tuna are taken, the season being from November to March. However, in this region there are practically no exploratory data for any season other than November to March, nor are there any vessels actually operating there except at this season, therefore, the occurrence of tuna at other seasons is completely unknown.

At almost the same time (November to March) that these sporadic catches have been made in the broad expanse to the east of 140° E. longitude, rather dense schools appear in waters around Tanegashima. The question of what route these schools follow before appearing in this area is not as yet concretely answered. However, judging from the changes in fishing conditions in this area and in other areas, it is thought that these are not already organized schools which have migrated in from other regions, but that the fish gradually congregate and form schools in this area. Up to the end of March these schools move extremely slowly with each succeeding day toward the northeast, but after the end of March, when they reach the waters of Miyazaki Prefecture, they suddenly disappear and the densely populated fishing grounds vanish. Hitherto the established theory has been that the schools follow the Japanese coast to the Northeastern Sea Area, but among the fishermen in the Aburatsu area there are some who claim that the direction of the migration shifts to the south from the vicinity of Toi Misaki (on the west coast of Kyūshū).

Around the end of the fishing season off southern Kyūshū, dense schools of black tuna appear in the northeastern portion of the South China Sea and fishing flourishes for an extremely short period on the east and west coasts of the island of Luzon. The peak of this fishery is in April and May, the fishing falling off rapidly in June. Judging from the changes in this fishery, it may be thought that the schools from this area gradually move along the Okinawa chain, but there is as yet no concrete proof that this is or is not the case.

At about the same period some black tuna are taken in the northern portion of the Ogasawara Islands area, and there is some catch in the waters off the Tokiwa region of eastern Honshū. It might be thought that this represents a movement of the schools which were densely congregated off southern Kyūshū, but if we consider the broad distribution this would entail, there is doubt as to whether or not the schools from the Tanegashima waters have become so widely distributed as to appear all over the whole area directly under the influence of the Kuroshio, from the waters off Luzon to the coasts of Japan proper, at almost the same time.

We have almost no data with which to investigate the relationship between the schools which appear around Tanegashima and those from the Luzon area, but they can be thought to be different schools in view of the following three points. The first point is the difference in the size of the fish. The schools which appeared around Tanegashima were mostly small fish of around 165 pounds in the early years of the Shōwa Era (1925 to 1930). With each succeeding year the fish have become larger and around 1940 their average weight was about 450 pounds (figure 13). Around Luzon the fish were very large when the fishery was first developed in 1935, with fish of 655 to 820 pounds in the early part of the season, gradually declining in size as the days passed until smaller fish of about 490 pounds were taken at the end of the season. It is very regrettable that there are no data to show this concretely. However, full account should be taken of this difference in the size of the individual fish.

The second point is the question of fishing seasons. As has already been said, about the time the schools in the waters around Tanegashima began to move slowly to the northeast, there was already a certain amount of fishing being done in the South China Sea. As was stated earlier, there is also a theory that the schools move south from the vicinity of Toi Misaki, and the coincidence of fishing seasons is not necessarily proof of the difference or identity of the schools. It is believed, however, that this coincidence of fishing seasons, together with the distance between the fishing grounds and the movements of the schools in the waters around Tanegashima, has a considerable significance as indicating the distinctness of the schools.

The third problem to be considered is the question of the sexual maturity of the two groups of schools. There have been absolutely no reports of fish with ripe or near-ripe gonads from the schools in the waters around Tanegashima, even at the end of the fishing season. It is believed that July is the center of the spawning season for black tuna in Japanese coastal waters (including the Japan Sea). In fish from the schools of the Luzon area the gonads are already very well developed at the beginning of the fishing season, in April and May the majority of the fish are ripe, and by the early part of June spawned-out fish already appear in the catch. As it is thought that these fish characteristically spawn over a rather long period and throughout a broad area, this difference in ripeness of the gonads cannot be said to have absolute significance as indicating the distinctness of the schools. Thus at present we have no data which would enable us to prove definitely the relationships between the schools which appear in these two areas and we must therefore wait for future studies to be made. However, the three points cited may be considered to indicate the distinctness rather than the identity of these schools.

B. Albacore

The appended chart II shows the distribution of catch rates for albacore. As has already been stated, the albacore is broadly and generally distributed in the western Pacific Ocean north of the Equator to the vicinity of 40° N. latitude and it also occurs to some extent in the South China Sea and the Sulu Sea. It can be said, however, that the area in which the catch rates are particularly great, or in other words where the density of distribution is high is the area from 25° to 40° N. latitude. Accordingly it can be said in extremely general terms that the main fishing grounds are in the area north of the Northern Equatorial Current, that is, north of 25° N., in the Kuroshio and its extension, the North Pacific Current.

Considered seasonally, this species occurs to some extent at all times of the year somewhere in the northern part of the western Pacific. The season of densest occurrence, however, is from November to March, particularly from December to February.

As our data are extremely uneven in their representation of areas and seasons, it is impossible to clarify the distributional pattern for each sea area throughout the year. If we select two or three sea areas for which data are comparatively adequate throughout the year, and plot the changes in the fishing conditions from month to month in those sea areas, we get the picture shown in the following figure.

Figure 15 shows the fishing situation in each month in the area 0° to 5° N., 150° to 160° E. In December, February, and March the catch rate is 0. Some fish are taken in all the other months, the catch gradually increasing from July on, with the highest catch rate of the year in September. The catch rate declines sharply in October, showing only a vestigial occurrence.

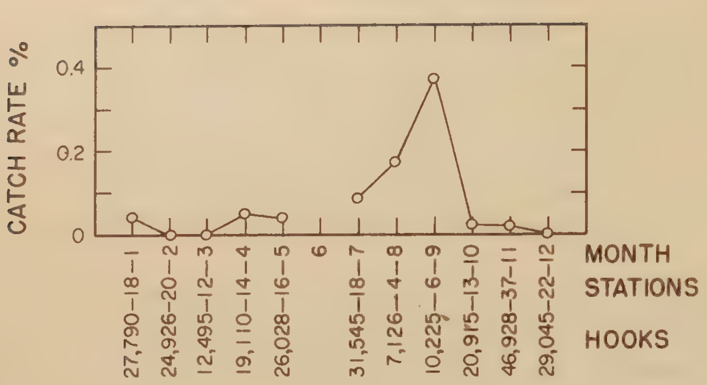

Figure 15.--Albacore fishing conditions in each month (0° to 5° N., 150° to 160° E.)

Figure 16 shows fishing conditions in the southern part of the Ogasawara Islands (20° to 25° N., 140° to 150° E.). Because of the scarcity of data, account must be taken of the error introduced by the operation of fluctuations in fishing conditions on the catch rate. However, the trend of the curve agrees well with that for the area closer to the Equator and the highest catch rate seems to occur in September.

The changes from month to month in albacore fishing conditions farther to the north in the area 30° to 35° N., 140° to 150° E. have already been shown in the section on the waters east of the Izu Islands, but for the convenience of the reader, these facts are plotted in the following graph.

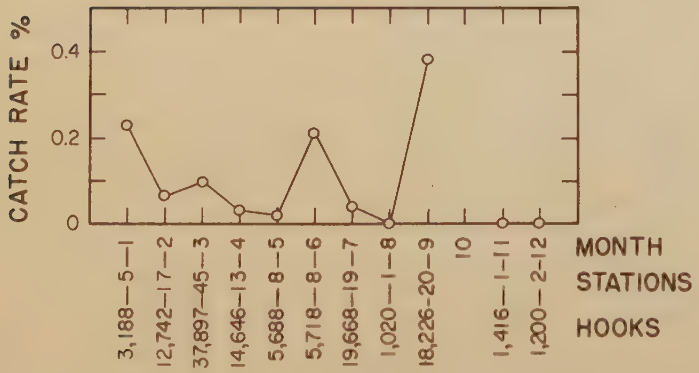

Figure 16.--Albacore fishing conditions in each month (20° to 25° N., 140° to 150° E.)

The data are inadequate for many parts of the curve, particularly in September, where data are completely lacking. When this graph is compared with the two previously presented, we not only see a remarkable increase in the catch rate itself but a complete change in the seasonal pattern of fishing. The catch rate rises steeply from November to January until it attains a figure of about 6.0. In February it drops somewhat, but is still remarkably high. From March on it falls off steeply and during the summer there is hardly any catch. A great deal of attention should probably be paid to the difference between these areas in any consideration of the distributions and migrations of the albacore. As was stated earlier, the albacore is densely distributed in the area of the Kuroshio and the North Pacific Current, the boundary of its distribution being known to be the subtropical convergence. Not only is there this remarkable change in fishing conditions as we pass the boundary of the subtropical convergence, but there is also a very marked change in the size of the fish. If we compare fish taken during the winter, we find that those caught south of the subtropical convergence are for the most part a great deal larger than those taken to the north of it.

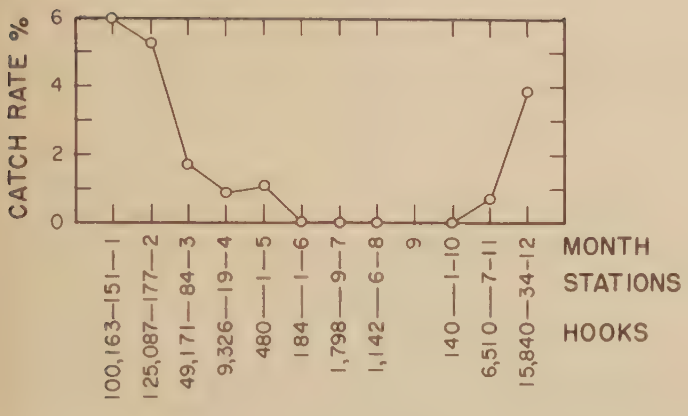

Figure 17.--Albacore fishing conditions in each month (30° to 35° N., 140° to 150° E.)

Monthly changes in the fishing conditions in the western Pacific north of 20° N. latitude in the period from November to March, which is the main fishing season, are shown graphically in the appended charts IIa-e.

In chart a (November) there appears to be an area of rather dense distribution 200 miles from east to west and 300 miles from north to south centered at 35° N. latitude, 150° E. longitude. There is no area of active fishing to the westward, nor does any area with high catch rates appear to the eastward as far as the vicinity of 150° E. longitude. East of 165° E. in the vicinity of 30° to 40° N. catch rates are high everywhere and a dense occurrence of albacore is indicated.

In chart b (December) the fishing grounds of the area centered around 150° E. are greatly extended compared with November. There is a series of excellent fishing grounds extending to the southwest from the vicinity of 38° N. to an area southeast of Hachijōjima at about 32° N., 141° E. Farther to the west there is an excellent but completely isolated fishing ground across the Izu Islands and south of Shionomisaki in the vicinity of 30° N. latitude. A tendency can be seen for the fishing grounds to broaden southeastward from the vicinity of 150° E., and the fishing is good over an extensive area along the parallel of 33° N. between 140° and 155° E. longitude. The center of the fishing grounds which appeared east of 165° E. in November has moved slightly to the southward and these grounds have extended towards the west, so that in terms of catch rates alone the boundary with the fishing grounds which appeared centered around 150° E. longitude has become completely obscured and the whole area centered around 35° N. latitude has become a good fishing ground.

In chart c (January) the center of the fishing grounds which were centered around 150° E. longitude has shifted to the southwest to the vicinity of 29° to 33° N., 143° to 147° E. In December the vicinity of 35° N. was the center of a fishing ground, but in January fishing has become remarkably poor north of 35° N. The isolated fishing ground which appeared in December south of Shionomisaki has become greatly enlarged and the catch rates are improved over those of December. East of 150° E. longitude there is little difference in the fishing situation from one area to another, the catch rates being everywhere about the same. Within the region for which we have data east of 150° E., the center of distribution has gradually moved southward, and east of 175° E., the center of distribution is south of 30° N. latitude.

When we come to chart d (February), we have much fewer data than we had for December and January, but on the whole there appears to be a tendency for the good fishing grounds to be isolated or scattered. On the west, the fishing ground south of Shionomisaki has become even more extensive than it was in January and the fishing is good there. Another fishing ground with rather high catch rates has appeared about 100 miles south of the Izu Peninsula, and another region of fairly good catch rates can be seen to the east of the Izu Islands in the vicinity of 31° to 34° N., 141° to 142° E. The fishing ground which was centered at 30° N., 145° E. in January appears to have moved to the southeast, with a good fishing ground in the vicinity of 28° to 31° N., 144° to 149° E. Between 150° and 160° E. there appears an area of high catch rates in the vicinity of 32° to 34° N., roughly in the center of this area, while somewhat to the south good fishing is also indicated around 26° to 27° N. The position of the fishing grounds at the center of this group is about 2° south of where it was in January. The question of whether these fishing grounds are connected or isolated cannot be answered because the data are scattered geographically. On the whole, fishing conditions east of 160° E. longitude show a distinct tendency to deteriorate from the levels reached in December and January.

Chart e (March), shows fishing generally much poorer than it was in February. The areas with high catch rates have shifted farther to the south than they were in February, with the principal fishing grounds between 27° and 30° N. latitude. The fishing grounds south of Shionomisaki have shifted to the southeast and their center is in the vicinity of 28° to 30° N., 136° to 139° E. Between 140° and 150° E. there is a fishing ground with rather high catch rates in the vicinity of 28° to 31° N. Eastward from 150° E. longitude to 165° E. there are hardly any data and the distributional pattern is not clear, but what data there are show a strongly fluctuating fishing situation with unstable catches. East of 165° E. the data are almost entirely confined to latitudes south of 30° N., and fishing is notably poor in comparison with February. The variation in catch rates between fishing operations is great and the catch is unstable.

The end of the longline fishing season in this area is around the end of March or the beginning of April, and almost no fishing is done after that time so there are practically no data. If however, we look at the few data we have for the period April to July, we see that from time to time during this period there are rather high catch rates and therefore we cannot believe that the albacore have entirely disappeared from the area. Because of the extreme paucity of the data, however, we cannot grasp the overall distributional pattern by means of longline catch rates.

During the summer albacore are taken almost entirely by pole and line. As a result the area covered by the fishing grounds coincides approximately with the fishing grounds for skipjack. As the fishing method employed at this season is completely different, it is not possible to make any comparisons of the density and pattern of distribution based on catch rates. Furthermore, the fish which are sought are generally for the most part young fish differing in size from the albacore taken in the longline fishery.

Uno[8/] has discussed the age composition of the albacore catch landed at Misaki in the summer. Uda[9/] has hypothesized the migrational routes for the albacore shown in the figure on the basis of the changes in the fishing conditions and the size of the fish taken in the longline and pole and line fisheries in 1935 and 1936. (The figure referred to has been omitted.)

The albacore taken by longlines during the winter from the waters of Japan's east coast to the area of Midway Island are thought to differ in size from area to area. In other words, it is thought that different age groups migrate within different regions. There are, however, data which indicate that there are rather marked variations from year to year in the size of the fish and in their growth and reproduction, and that fish of the same size are not always necessarily taken in the same fishing ground at the same season.

In the data used in preparing this book, records of the size of the fish taken are very few, and for this reason it is difficult to clarify the differences in distribution and the migrational patterns of the fish by reference to their size. Consequently, I have only been able to discuss

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8/ Uno, Michio. Composition of the catch of the tuna pole and line fishery east of Cape Nojima. Bull. Jap. Soc. Sci. Fish., Vol. 4, No. 5, pp. 307-309. 1936.

9/ Uda, Michitaka. The relationship of albacore fishing conditions to oceanographic conditions. Bull. Jap. Soc. Sci. Fish., Vol. 5, No. 5, pp. 295-300. 1937.

distribution and migration on the basis of catch rates. If we compare the charts a to e referred to above with the chart of migrations prepared by Uda,

1. At the beginning of the fishing season there are three groups of fish appearing separately in different areas. That is, in November the area centered around 150° E. and that centered at 165° E. each have one group, but in December the boundary between these two groups becomes unclear, while in the Kinan sea area, a group of schools completely separate from these two appears.

2. The subtropical convergence is a boundary, with the distribution of albacore to the south, that is, in the North Equatorial Current, quite vestigial, while the distribution is extremely dense to the north of the convergence.

   On these most important points, there is clearly agreement. However, with regard to the migration routes,

3. It is difficult to detect with certainty any fixed direction except that the schools to the east of 165° E. longitude are already densely congregated in the vicinity of 30° N. by the middle of November, and both the schools distributed around 150° E. and those around 165° E. move slowly to the south with the passage of time. It can be seen that the schools in the vicinity of 150° E. tend to move to the southeast.

4. On the whole the schools appear to become gradually densely congregated within an area just like a rising tide, but the migrational routes by which the schools move there are not clear. This tendency appears most clearly in the Kinan sea area.

Thus, certain differences are apparent, however, Uda's conclusions are based on data from only about 1 year, while the data presented here cover a number of years, in some cases more than 10 years, and therefore it may be thought that differences from year to year in the pattern of migration may have obscured the migrational routes.

As was stated earlier, it is impossible under present conditions to correct the catch rates for differences resulting from the fishing gear. The longlines used on fishing grounds south of 30° N., particularly fishing grounds in the vicinity of islands, differ somewhat, as has been said, from the gear especially designed to take albacore. It is, however, probably no mistake to consider that the differences in catch rates in waters north of the North Equatorial Current and in those to the south clearly indicate a difference in the density of distribution of the albacore.

C. Bigeye Tuna

Appendix chart III shows the distribution of catch rates for bigeye tuna in the Indian Ocean, the western Pacific, and their contiguous sea areas. As the chart makes clear, the distribution of the bigeye tuna is extremely broad, extending from the Equator to 40° N. Little difference in the density of distribution throughout the whole region can be seen from the catch rates. In other words, the center of distribution is not clear.

The chart represents catch rates throughout the year, and shows that the catch rates in the South China Sea are greater than those in the Sulu Sea and the Celebes Sea. Leaving these contiguous waters out of consideration, the general picture in the Pacific is as follows:

1. South of 10° N. there is an area off Mindanao where the catch rates are rather high, and farther to the east from about 140° to 160° E. there is another area of high catch rates.

2. There are very few data for the latitudes between 10° and 20° N. so that the situation there is not well understood, however, areas with high catch rates appear in these latitudes in the vicinity of 135° E. and again between 145° and 155° E.

3. Farther to the north the catch rates are high in a rather broad area centered around 155° E. and in the waters east of 165° E.

4. In all of these cases, it appears that one can detect a tendency for the catch rates to increase as one goes eastward.

The foregoing remarks take no account of the uneven seasonal distribution of the data. Seasonal changes in the density of distribution cannot be thoroughly investigated because of this characteristic of the data, but the general outline of the distribution as between the various sea areas is as follows.

The following figures show graphically the changes from month to month in fishing conditions in the South China Sea. There are no data at all for April and May and very little for August. Within the range covered by the available data, there is no catch at all from June to August, while there is a rather conspicuous peak in September with a catch rate of 0.35. In October and November the catch rate gradually declines only to increase again in December. The highest catch rates of the year are reached in February with a figure of 0.53.

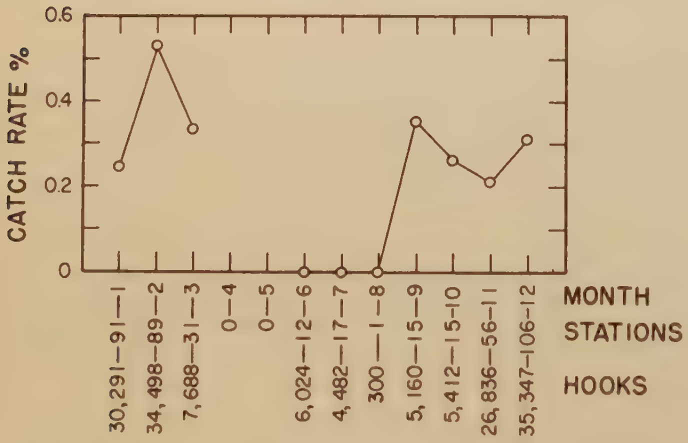


Figure 19.--Bigeye tuna fishing conditions by months

Data for such contiguous waters of the South China Sea as the waters east of Formosa, the Sulu Sea, and the Celebes Sea are unevenly distributed seasonally and therefore it is not possible to compare the monthly changes in the fishing conditions in these waters with those of the South China Sea.

Fishing conditions by months in the vicinity of the Equator from 0° to 5° N. and from 150° to 160° E. are shown in figure 20. The number of stations fished and the number of hooks employed are shown in the figure in the same manner as in figure 15.

Data are completely lacking for June. The catch rate reaches its low in March with a figure of only 0.02. Thereafter it shows a tendency to gradually increase and in September it reaches its highest point of the year with a rate of about 1.5. In October it drops off sharply and hits a low again in November, increasing slightly again from December to January and showing little difference between January and February. If this is compared with the curve for the South China Sea, there is agreement in the peak in September, but the January peak appears in February in the South China Sea. A conspicuous low appears in this area in March, but it seems to appear in the South China Sea after April.

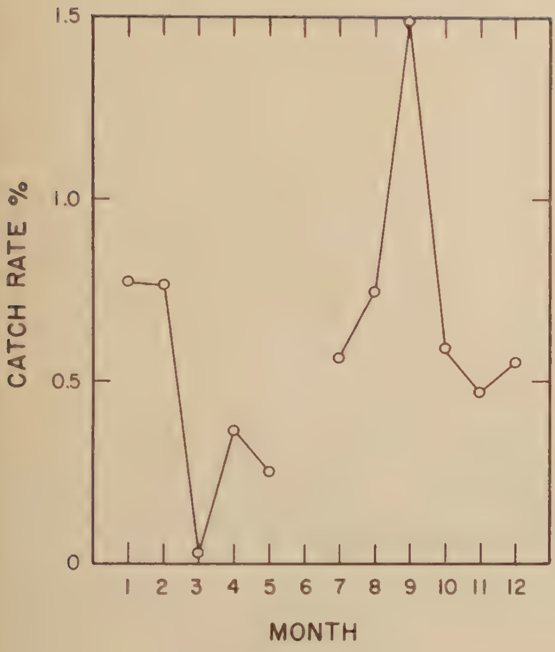


Figure 20.--Bigeye fishing conditions by months

As we have almost no data for the area from 10° to 20° N., it is impossible to make any comparison with changes in fishing conditions throughout the year there.

For the area from 20° to 25° N., 140° to 150° E., that is, from the southern Ogasawara Islands to the northern Marianas and eastward the data are summarized in figure 21.

As the figure shows, in this sea area catch rates for May and June are 0.0, but a rather conspicuous peak is seen in July. From July through September the catch rates continue to drop, and although there are no data for October, the catch rate continues to climb from the September low until it reaches the highest point of the year in January with a figure of slightly over 1.0. From February to May the catch rate falls off sharply.

The pattern shown by this curve differs rather markedly from that for equatorial waters, with a lag of 1 to 2 months, and it appears to show a trend which rather approximates the curve for the South China Sea.

Continuing to the northward, the fishing conditions by months for bigeye tuna in the area 30° to 35° N., 140° to 150° E., to the east of the Izu Islands, is shown in the following figure. The situation shown here differs conspicuously from that previously shown for the area south of the Ogasawara Islands. In this area the highest catch rates for the year appear as a sharp peak in April. From April to June the catch rates drop off sharply, but a low peak appears in July. However, our data for May and June are so few that it is not possible to decide whether or not the curve reaches a low point in June. From January on the catch rate gradually increases, with a blunt peak appearing again from December to January.

If this curve is compared with that for the area south of the Ogasawara group, there is agreement in the appearance in peaks in January. However, in the area south of the Ogasawaras this peak is extremely conspicuous, while in this area it is blunt and inconspicuous. The most outstanding peak in this area appears in April, and in this month the catch rate south of the Ogasawara Islands shows extremely small values. Small peaks appear in both areas in July, but as was said earlier, it is doubtful whether or not that which occurs in the curve for this area is really a peak at all.

Farther to the north the data are almost entirely confined to the winter and therefore the monthly changes in the fishing conditions throughout the year are not clear. As was already stated in the section on fishing grounds, the pattern of bigeye tuna fishing in this region varies from area to area, but in general the catch rates reach their highest point in November or December.

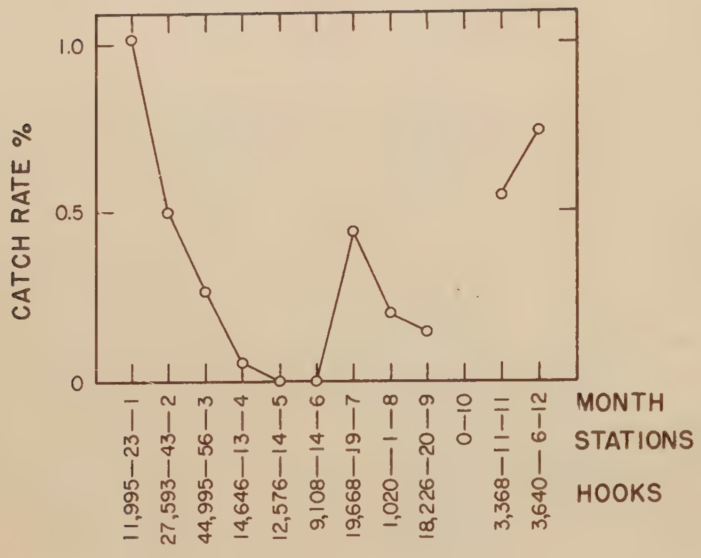
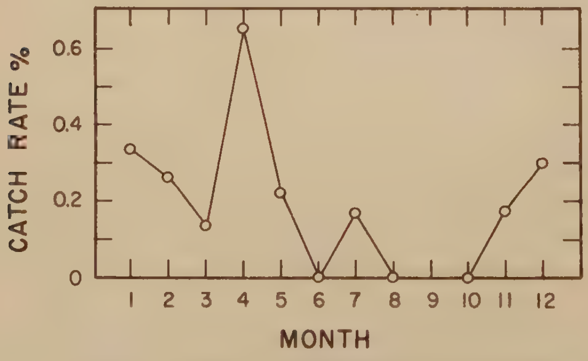


Figure 21.--Bigeye tuna fishing conditions by months (20° to 25° N., 140° to 155° E.)

Figure 23 shows the changes in fishing conditions by months for the waters of the Okinawa Islands, where the oceanographical environment differs more or less from that of other sea areas. The form of the curve somewhat resembles that for the waters south of the Ogasawaras. In the latter area, however, a second peak appears in July and no such peak appears in this area. There seems to be a blunt peak appearing around April and May, but it is extremely unclear.

As the foregoing figures show, the monthly changes in fishing conditions for bigeye tuna differ rather strikingly between areas, just as they did in the case of the albacore. Not only do they differ with respect to the months having the highest and lowest catch rates, but the values of the catch rates themselves differ markedly. However, in spite of the fact that the positions of the peaks and low points on the curves of monthly catch rates differ and despite the differences in the catch rates themselves, it seems possible to detect a common character more or less clearly shared by all of the curves for the various areas. For example, the catch rates begin to drop off sharply in the month after the highest catch rates are attained, and they reach their lowest point about half a year later with no catch or almost none. One or two months after the month in which the lowest point is reached, a secondary peak appears, and thereafter the catch rates gradually decline until one or two months before the month in which the catch rates reach their highest point. During this latter period there is no month without some catch. In other words, there are two peaks and two low points in the year, the period between the maximum and minimum catch rates being about half a year, and a second peak and the second low make their appearance during the half year between the minimum and the maximum. In the vicinity of the Equator from 0° to 5° N., and from 150° to 160° E., and in the Nankai sea area from 25° to 30° N., 130° to 140° E., this relationship is reversed, with the secondary peak and the secondary low



NOTE: NUMBERS OF STATIONS AND HOOKS SAME AS IN FIG. 15.

Figure 22.--Bigeye tuna fishing conditions by months (30° to 35° N., 140° to 150° E.)

appearing in the months between the maximum and the minimum, and with a tendency for the catch rates to increase gradually in the period extending from the minimum to the maximum. All of these areas, however, share the characteristic of two peaks and two lows in the catch rates in the course of a year.

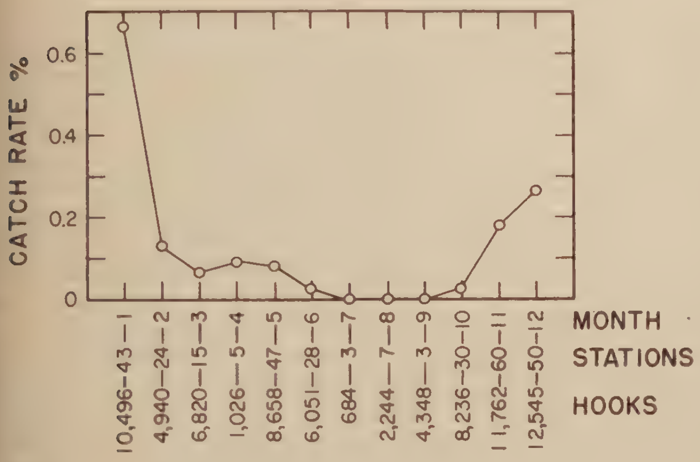


Figure 23.--Bigeye tuna fishing conditions by months (24° to 30° N., 120° to 130° E.)

The significance of these two types of catch rate curves is not clear at present. Furthermore, the problem of whether these two types indicate conditions prevailing at all times within the respective sea areas or whether they simply reflect an error due to the abundance or scarcity of the data can only be answered when future investigations have amplified the data and when not only comparisons of the fish catch rates but comparisons of the body dimensions of the fish have been thoroughly made. Thus at present it is difficult to come to a decision concerning this question, but problems of this sort can be thought to have an extremely important significance in the study of bigeye tuna resources, distribution, and migration.

D. Yellowfin

Appendix chart IV shows the distribution of catch rates throughout the year for ellowfin tuna. As is clear from the chart, the distribution of yellowfin is also extremely broad, xtending from the Equator to the vicinity of 40° N. latitude. The species also occurs widely n the South China Sea, the Sulu Sea, the Celebes Sea, the Flores Sea, and similar enclosed waters. Areas with a high density of occurrence are, however, almost entirely limited to the waters of low latitudes, the distribution of this species in the high latitudes being almost vestigial. Consequently, the longline fishing grounds for yellowfin tuna are almost confined to the low latitudes.

Areas with a high density of occurrence, where catch rates are 5.0 or above, can be ery broadly said to be south of 3° N. in the Pacific Ocean. Off the east and west coasts of the Philippine Islands, however, such areas extend farther north, waters with catch rates of 5.0 or more appearing as far north as 10°N. off the east coast. In such enclosed waters as the Celebes, ulu, and South China seas the density of distribution is generally high and waters with catch ates above 5.0 can be found as far north as 20° N. In any case, in the western North Pacific he productively significant range of occurrence of yellowfin tuna can be considered to be south f 10° N. latitude.

The situation in the Southwest Pacific and Indian Ocean regions is not well known ecause of the paucity of data from these areas, but in the Solomon Islands area it appears that, s might be expected, the density of occurrence is greater in tqe low latitudes (sic) than it is outh of 5° S. The data from the Banda Sea, the Flores Sea, and the waters of the Greater and esser Sunda archipelagoes represent chiefly the season of northwesterly winds (the southern ummer), but in this region areas with catch rates of 5.0 or more extend southward to 12° S.

It is thought that this situation is controlled mainly by such geographical factors as the arrangement of islands.

The following figures show catch-rate curves for each month for the yellowfin tuna in areas for which data are fairly abundant throughout the year, just as was done in the case of the albacore and the bigeye tuna.

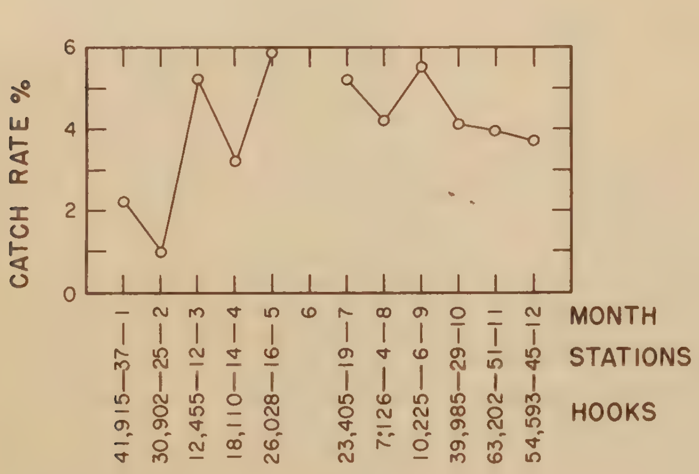


Figure 24.--Yellowfin tuna fishing conditions by months (0° to 10° N., 150° to 160° E.)

Figure 24 is a catch rate curve by months for the area extending from 0° to 10° N. latitude and from 150° to 160° E. longitude. The peaks on the curve appear quite clearly in March and September. We have no data at all for June, but it appears that the highest catch rates for the year occur in May and June. The minimum catch rate for the year appears in February, with a fairly clearly defined low in April and another less clear in August. From October to December the fishing is comparatively stabilized, with catch rates of about 4.0. As there are almost no cases in which data for the whole year are available for particular areas, the monthly changes in the fishing conditions in waters to the east and west of this area are not known, however, in some cases rather high catch rates are indicated in February and April so that it seems difficult to believe that these changes take place uniformly in the equatorial waters of the western Pacific. It is impossible to determine at present whether these changes indicate local differences in the fishing season or whether they are completely fortuitous.

Figure 25 shows the yellowfin fishing conditions by months for the vicinity of Palau, 7° to 8° N. latitude, 133° to 135° E. longitude. The data cannot be said to be complete, however, the figure shows the peaks on the curve to appear in May, October, and December. The May and December peaks are particularly conspicuous. The low points on the curve appear in March, July, and November, that in March being extremely conspicuous. Comparing this figure with the preceding graph, we find that the latter had peaks in March, May, June, and September with lows in February, April, and August. Thus the conspicuous peaks of May generally coincide, but the December peak did not appear in the former figure, and the other peaks and low points, with some lag, appear with about 1 month's difference.

Figure 26 shows the fishing conditions by months in the South China Sea. Data are completely lacking for April and May and therefore the year-round pattern is not known. There is an extremely conspicuous peak in October, but no outstanding differences in the fishing conditions can be detected from November to about March. There appears, however, to be a rather marked low point in January. The catch rate is at its lowest in August, a month for which we have few data. There are no data at all for April and May, but if we assume that there is a pronounced peak in May, the form of the curve would closely resemble that for Palau waters. If we further assume that the catch rate gradually declined from March to August, the curve would have two peaks and two low points and would show the same trend as the monthly catch rate curve for bigeye tuna.

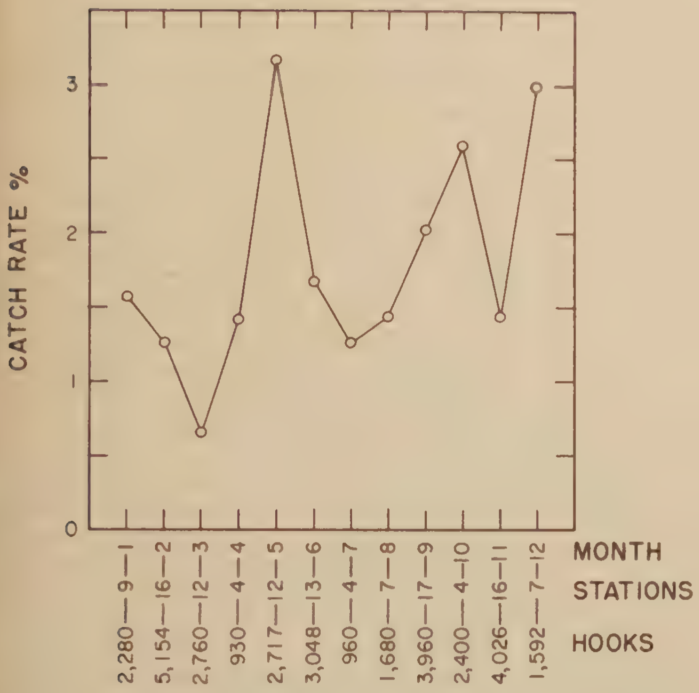


Figure 25.--Yellowfin fishing conditions by months, Palau waters (7° to 8° N., 133° to 135° E.)

Figure 27 is a curve of monthly catch rates for yellowfin tuna in the area south of Japan between 25° and 30° N., 130° and 140° E. Data are completely lacking for August and September. As may be seen in the figure, the catch rates are much lower than in all of the sea areas previously treated. There is a very outstanding peak in October falling off sharply from November on. There are no marked changes from January to March, the low point of the year being reached in April. The catch rate is low in May, but a more or less conspicuous peak does appear. The October high coincides with that of the South China Sea, while the May peak coincides with that of the equatorial region. On the whole it is assumed that the form of the curve approximates that for the South China Sea.

Figure 28 shows the monthly fishing conditions for yellowfin in the area from the Marianas Islands to the southern part of the Ogasawara archipelago. Data are lacking for the month of October.

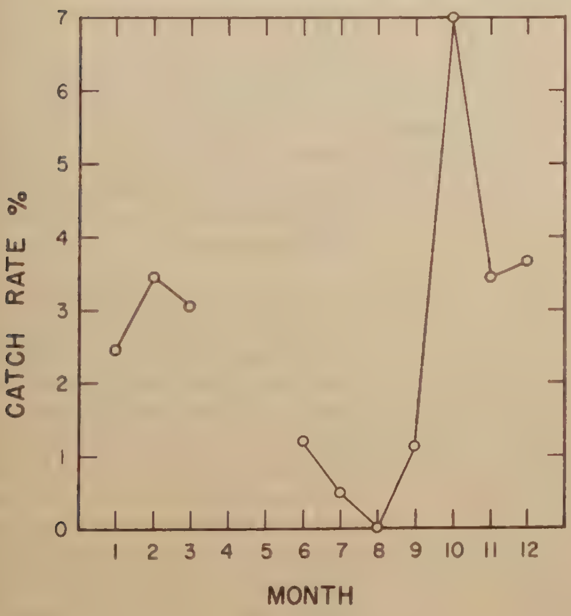


Figure 26.--Yellowfin tuna fishing conditions by months, South China Sea

As the figure shows, the maximum catch rate of the year for this area appears in December. From January through February the catch rate drops off sharply, with a low point in the latter month. In March and April it shows a tendency to rise somewhat, and in May a rather conspicuous secondary peak appears. Thereafter the catch rate again declines and reaches the low point of the year in July. As we have no data for October, it is not known whether a peak would appear in that month as it did in the various other sea areas. Comparing this figure with the curves for the various other sea areas already described, we find them completely alike in respect to the peak appearing in May. From the trend of the curve, it is difficult to think that a peak would appear in October, and in this respect the curve differs from those for other areas. Except for the

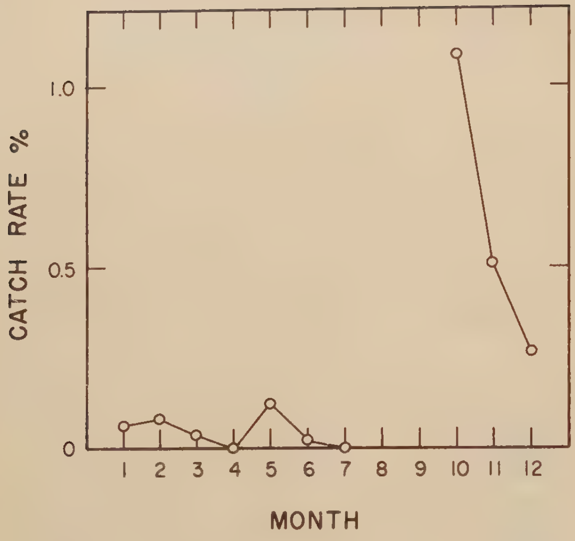


Figure 27.--Yellowfin fishing conditions by months (25° to 30° N., 130° to 140° E.)

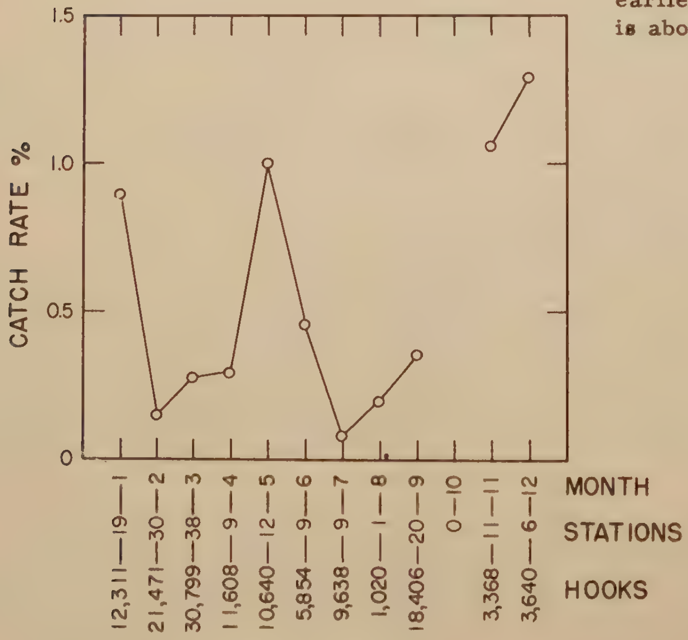


Figure 28.--Yellowfin fishing conditions by months (19° to 24° N., 140° to 155° E.)

situation existing in October, the form of this curve tends to coincide with that for Palau waters. It also shows a tendency to agree quite well with the monthly fishing conditions for bigeye tuna described above.

Figure 29 shows the monthly fishing conditions for yellowfin tuna in the area east of the Ogasawara Islands and connecting with the northern part of the area treated in the preceding figure. This figure shows the maximum catch rate in this area to occur in July with the secondary peak in November. The low points in the curve appear in January and October, with the January minimum being the lowest.

If this is compared with the preceding figure, the conspicuous peak which appeared in May, here appears in July, a difference of 2 months. The preceding sea area showed a peak in December, but in this sea area it appears 1 month earlier in November. The low points on the curve occurred in February and July in the preceding area, while in this area they are in January and October. The winter low is 1 month earlier in this area, while the summer low is about 3 months later. Although there are these seasonal differences between the two areas, the forms of the curves as a whole are in agreement, and they appear to have something in common with the curves for the bigeye tuna in the low latitude sea areas. As for the seasonal lag between the two areas, it may be thought that there is a lag in the time of the north-south migrations of the schools.

It is impossible to reach any definite decision on the basis of the amount of data available, however, it is thought that a difference in the migrational pattern of yellowfin tuna to the east and west of the line formed by the Izu Islands, the Ogasawara Islands, the Mariana Islands, and the Carolines can be detected. We cannot thoroughly examine the presence or absence of such a difference because of the scarcity and uneven distribution of the data.

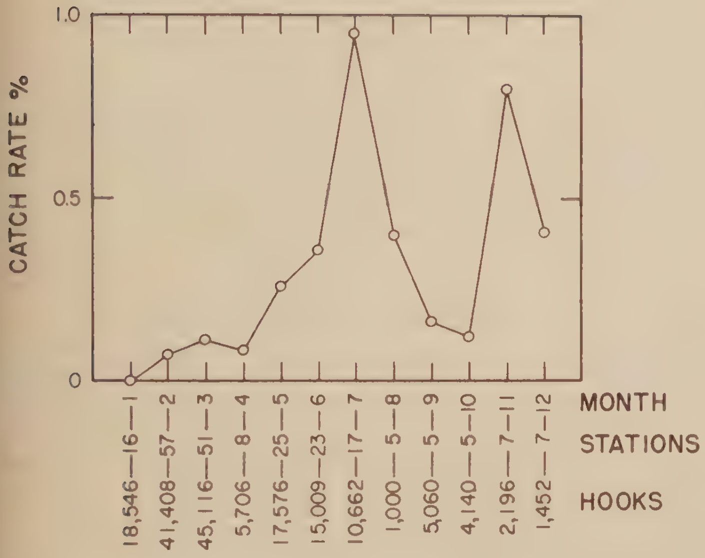


Figure 29.--Yellowfin tuna fishing conditions by months (24° to 30° N., 140° to 150° E.)

As we proceed farther north the yellowfin catch becomes extremely small and the seasonal distribution of the data becomes extremely uneven, for which reason we cannot discuss the distribution of the fish as shown by the catch rates. It appears, however, that the highest catch rates of the year occur in September and October, with only one peak in the curve during the year. This trend becomes more marked the farther north we go, and a tendency can also be detected for the peak to appear earlier. These facts are believed to indicate that we have reached or are approaching the limits of migration and distribution of this species.

Comparing the catch rate curves for the various sea areas described above, one can see considerable regional differences in the seasons at which the peaks and low points appear. There are cases like that of the area east of the Ogasawara Islands and the area east of the Mariana Islands, where such differences can be thought to indicate directly the movements and migrations of the schools, but it is difficult to grasp the direction of motion of these schools by means of these curves.

A peak appears in May through the whole area from 25° N., south to the Equator (the situation in the South China Sea is unknown because of the lack of data), and it is impossible to detect any trend which would indicate local movements of the schools from one region to another. In the waters to the west of the Izu, Ogasawara, Mariana, and Caroline archipelagoes a conspicuous peak appears everywhere in October. In addition to this commonly-shared peak, each area's curve shows a second peak, but the season in which the secondary peaks appear seems to vary greatly between areas.

In the case of the bigeye tuna it was stated that some agreement in the trend of the curves as a whole could be detected, even though there were seasonal differences in the position of the peaks and low points. The same sort of relationship can be detected in the case of the yellowfin tuna. The fact that the trends of the curves show resemblances between areas not only for the yellowfin but for a different species, the bigeye tuna, should have an extremely important significance in studying the distribution and migration of these fishes and the presence or absence of sub-species.

It has already been mentioned several times that the density of distribution of yellowfin tuna is high in the vicinity of the Equator and drops off as one goes into the high latitudes. The following graph shows catch rates for yellowfin in blocks of 10° of longitude and 2° of latitude between 120° and 160° E. longitude. Material from the Sulu Sea, the Celebes Sea, and the South China Sea, where environmental conditions are different, has been left out of the data for the area between 120° and 130° E. longitude.

As the figure shows, the catch rates are highest near the Equator, falling off sharply to the north, with the low point in the vicinity of 12° to 14° N. North of this latitude, the curve slowly rises again and there is a blunt peak in the vicinity of 18° to 20° N. North of this latitude, the curve again drops off steeply and from 30° N. latitude on to the northward the catch rate is practically zero, indicating only a vestigial occurrence of the species.

Thus the various curves taken together show a general trend, but there are regional differences of some extent in the position of the peaks and low points and also in their magnitudes. There are also cases like that of the area between 120° and 130° E. longitude where the inclination of the curve is conspicuously gentler than in other regions.

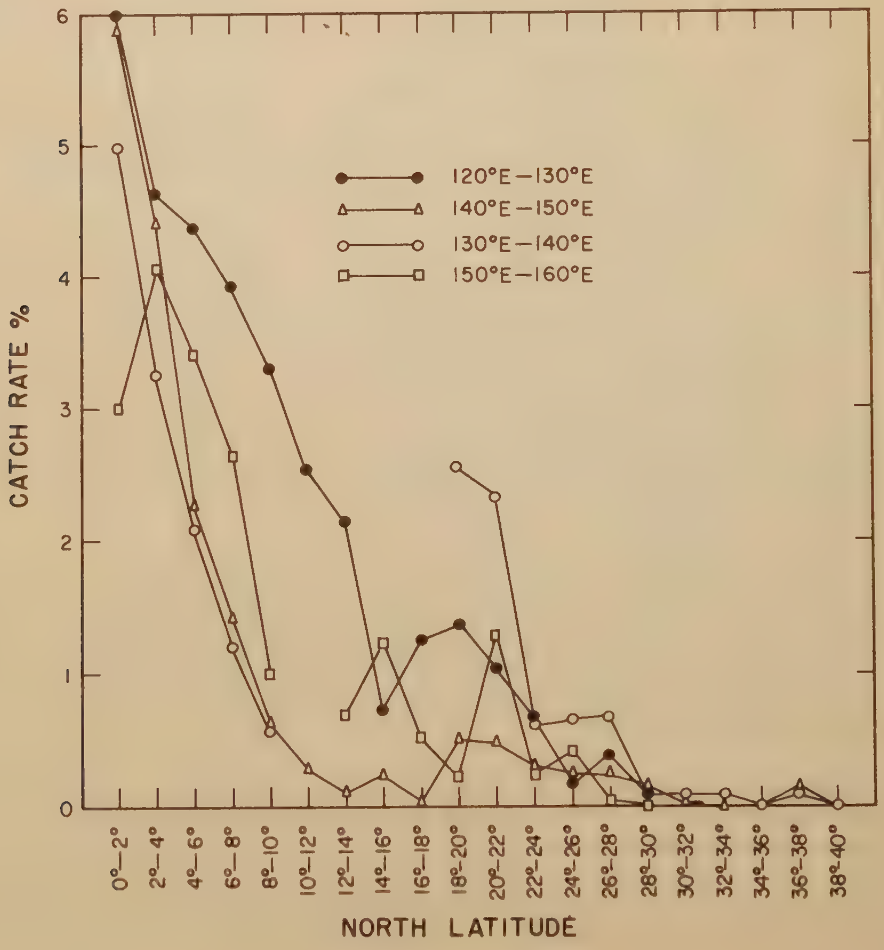


Figure 30.--Fishing conditions at different latitudes (yellowfin tuna)

As has already been stated, seasonal changes are apparent in the density of occurrence of the yellowfin. The data used in this figure are not equally representative of all seasons in all regions but show a marked tendency toward an uneven distribution. As the curve in this figure is a summarization of past data, with absolutely no account taken of seasons, there is naturally a need for correction based on a consideration of the data by seasons. Such a correction would probably change to some extent the magnitude and positions of the peaks on the curve and the differences in their slopes, but it can hardly be thought that it would give rise to conspicuous changes in the general trend of the curves. Therefore, this figure can probably be regarded as showing in general outline the distributional pattern of the yellowfin tuna in the northwestern Pacific Ocean as it relates to latitude. Because of the lack of fish measurements and other data, it is impossible to come to any decision at present concerning the relationships between the schools which make up the peak of the catch rate, that is of the density of distribution in the area centered around 20° N. latitude and the schools which make up the peak in the low latitude area centered around the Equator. Thus we cannot in the absence of further study come to any conclusions concerning such important questions as whether or not these schools belong to different stocks, whether they belong to the same stock but represent different age compositions, or whether fish of exactly the same stock have, because of oceanographic conditions or their relationships with other aquatic life, formed two centers of distribution where the density of occurrence is high in comparison with the surrounding waters. However, the phenomena of a generally improving catch rate throughout the area south of 25° N. in May and a similar simultaneous rise in the catch rates in the area west of 140° E. longitude in October are considered to be data which tend to deny the validity of the idea that there are a large number of stocks in the western Pacific region.

E. Spearfishes

Chart V shows the distribution of spearfish catch rates throughout the year. In the chart all of the spearfishes are lumped together.

If we look at the areas on the chart where the catch rates are over 1.0, we see that they include almost all of the Celebes Sea, the coastal waters on the east side of the Philippine Islands, Formosa and Okinawa, the vicinity of 7° to 10° N., 140° to 150° E., and the waters around the Izu, Ogasawara, and Mariana islands. Catch rates are also over 1.0 in the areas centered around 35° to 40° N., 150° to 160° E. Other sea areas where the catch rates are high are in the Kinan sea area and in the vicinity of 29° to 39° N. at 100° E. Other fishing grounds with comparatively high catch rates can be recognized south of 10° N. in the vicinity of 155° to 160° E. There are almost no data worth considering from the operations of research vessels, but judging by the reports of commercial vessels the Marshall Islands region also appears to be a superior fishing ground for spearfishes. From the foregoing it is seen that, with the exception of the broadbill swordfish, the good fishing grounds for other spearfish species are in waters comparatively close to islands or the continental shelf.

As for the catch by species, there are many cases in which it is impossible to tell because of deficiencies in the data, but in general it may be said that the waters adjacent to Formosa have an abundance of white marlin that is unparalleled elsewhere. Sailfish are also extremely abundant. The proportions of spearfish species in the catch are shown in the following table.

Table 114.--Catch by species in Formosa (Takao and Suō fish markets, 1943)

Place	Total number of fish	White marlin	Black marlin	Striped marlin	Sailfish
Takao	16,461	2,542	5,373	645	7,901
Suō	6,944	4,448	161	742	1,593
Total	23,405	6,990	5,534	1,387	9,494

As the table shows, the composition of the catches at Suō and Takao are quite remarkably different. In the total for both ports sailfish were most abundant, making up slightly over 40 percent of the total catch, while white marlin were slightly under 30 percent, black marlin slightly under 24 percent, and striped marlin slightly under 6 percent of the whole.

In the various sea areas toward the center of the Pacific the proportion of white marlin is very small and that of black marlin and striped marlin is higher. It is believed that this shows that the center of the distribution of white marlin is in the extreme western Pacific and in the adjacent waters of the South China Sea, Sulu Sea, and the Celebes Sea.

Toward the center of the Pacific Ocean the striped marlin, black marlin, and broadbill swordfish are most commonly taken. The centers of the distribution of these species appear to be determined principally by latitude.

The following figure shows the catch rates for each section of 2° of latitude between 140° and 150° E.

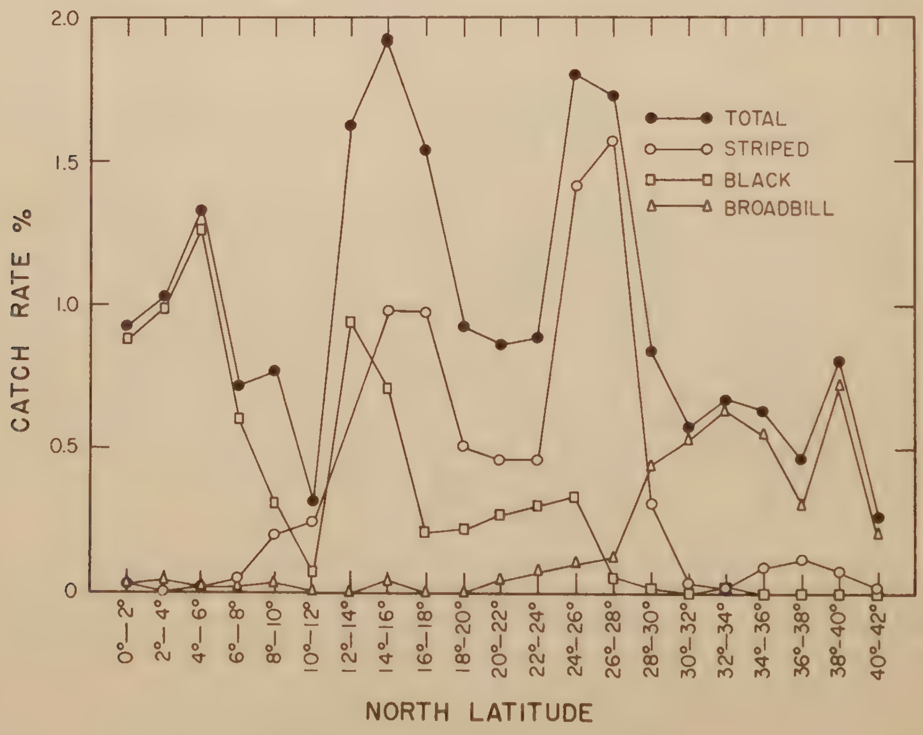


Figure 31.--Distribution of spearfish catch rates by latitude (0° to 40° N., 140° to 150° E.)

As the figure shows, for the spearfishes as a whole the peaks on the catch rate curve appear at 4° to 6° N., 14° to 16° N., 24° to 26° N., and 32° to 36° N., or at about every 10° of latitude. There is another fairly conspicuous peak at 37° to 40° N., but all of these more northerly peaks are composed of broadbill swordfish so it is doubtful whether they represent separate peaks or not.

The low points on the curve appear at 10° to 12° N., 20° to 22° N., 30° to 32° N., and 40° to 42° N., being separated by about 10° of latitude just as were the peaks. Among these various low points, it is doubtful whether the one at 10° to 12° N. is really as pronounced as it appears on the figure because there are very few data for this area. It is also thought worthy of note that the position of this low coincides perfectly with that on the yellowfin curve.

The peak on this curve which appears at 4° to 6° N. is almost entirely composed of black marlin, while that which appears at 14° to 16° N. is composed of black marlin and striped marlin. The peak appearing at 24° to 28° N. is composed almost exclusively of striped marlin while the peaks north of 30° N. are formed for the most part of broadbill swordfish. Consequently, to state it very broadly, we can recognize a successive distribution from south to north of black marlin, striped marlin, and broadbill swordfish. In the following figures the variations in fishing conditions from month to month are shown for each sea area, just as was done in the case of yellowfin and bigeye tuna.

First of all, figure 32 shows the situation in the vicinity of the Equator from 0° to 5° N. and from 150° to 160° E.

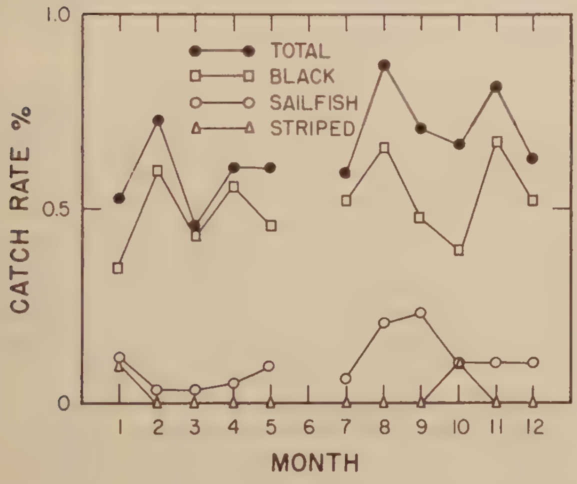


Figure 32.--Spearfish fishing conditions by months (0° to 5° N., 150° to 160° E.)

The increases and decreases in the catch rates are not very conspicuous, but in the catch rate for the spearfishes as a whole the peaks appear in February, August, and November. The catch is almost entirely made up of black marlin, with sailfish next in abundance and striped marlin extremely scarce. There are no data for June, but the sailfish appear to increase somewhat around August and September. Striped marlin become somewhat more numerous in January and October.

Figure 33 shows the fishing conditions in the waters around Palau.

As the figure shows, the peaks on the curve are in April, October, and December-January. The catch of each species is not known so we cannot show what these peaks are composed of, but from the form of the curve, it is difficult to conclude that they are all the same species. Compared with the preceding figure, the positions of the peaks and lows on the curve are quite conspicuously different.

Figure 34 gives the fishing conditions from 19° to 24° N., 140° to 155°.E., i.e., to the east of the area between the northern Marianas and the southern Volcano Islands.

For the total catch, the peaks on the curve appear in January, March, May, and August. They have been omitted from the figure, but from December to February broadbill swordfish increase somewhat in abundance. Striped marlin increase gradually from November on and form a rather conspicuous peak in March. In April they decline quite rapidly, but increase again sharply in May to attain their maximum catch rates of the year. From June on they drop off steeply and reach their low of the year in August.

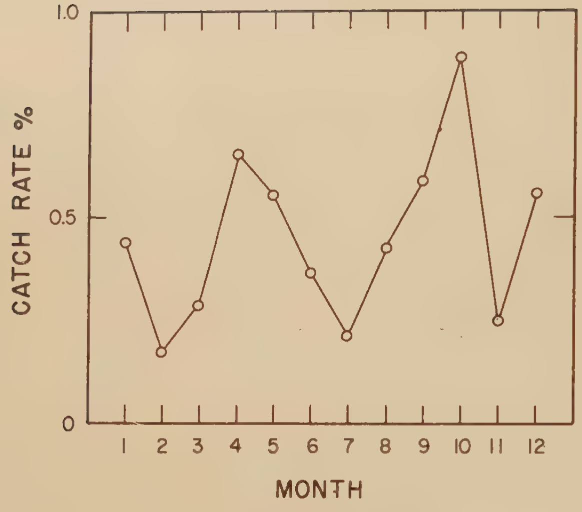


Figure 33.--Spearfish fishing conditions by months, Palau waters (7° to 8° N., 133° to 135° E.)

The black marlin catch rates do not change much from January to May. From June to August they increase gradually and attain their peak for the year in the latter month. In September they drop off sharply, and although there are no data for October, the low of the year appears to be reached about December. The area within which the black marlin has quite an important significance as an element in the longline catch extends generally to the vicinity of 25° N. Above this latitude there appear to be no fishing grounds on which the catch rate for this species gets above 1.0.

Because of the lack of data we cannot make any comparison between sea areas at the same latitudes, but the changes in fishing conditions for black marlin and striped marlin by months at Takao in Formosa are shown in the following tables.

The areas fished by boats based at Takao are at approximately the same latitude or somewhat to the south of the area covered by the preceding figure, and during the winter the South China Sea is the principal fishing ground. Because the number of vessels in operation is not known, it is not clear what the fishing effort was. Consequently the comparison of the number of fish landed in each month as shown in table 115 and 116 does not have the same significance as the increases and decreases shown in the preceding figure of the catch rate curves. For example, although the minimum number of fish caught appears in September, it is not known whether the number of vessels operating was the same as in the other months and the catch was actually down, or whether the number of fish taken decreased because of a decrease in the number of vessels operating.

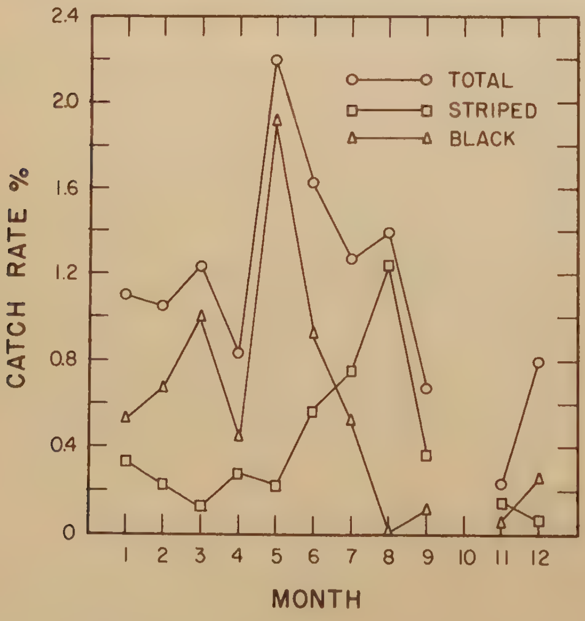


Figure 34.--Spearfish fishing conditions by months (19° to 24° N., 140° to 155° E.)

Such factors must be taken into consideration, but it appears from table 115 that at Takao the catch of black marlin was at its peak in July and at its lowest in September. The second peak appears in November and a second low around March. There appears to be a third peak in May, but it is not very clear.

Table 115.--Numbers of fish by weight classes landed by months at Takao in 1943 (from Nakamura in the Journal of the Formosan Natural History Society, Vol. 34, No. 251)

Weight in kg	Black marlin												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
10-20	0	0	0	0	0	0	0	0	0	1	2	1	4
20-30	2	2	1	0	1	6	2	1	1	1	2	0	19
30-40	2	2	1	6	30	48	111	108	4	9	19	9	349
40-50	5	10	7	13	96	129	460	199	11	55	59	26	1,070
50-60	28	20	20	33	78	60	214	110	15	73	59	40	750
60-70	26	29	22	16	45	55	120	59	16	49	98	80	615
70-80	39	39	20	12	43	24	50	29	12	29	87	56	440
80-90	43	27	22	21	26	11	39	23	12	25	30	23	302
90-100	22	24	17	18	33	11	42	29	25	14	16	23	274
100-110	19	18	14	24	41	22	37	31	21	19	14	22	282
110-120	18	19	25	17	32	21	40	28	29	16	15	22	282
120-130	13	13	16	20	23	9	28	14	14	23	13	14	200
130-140	12	14	19	25	23	14	21	21	14	22	9	20	214
140-150	8	15	11	13	28	13	30	13	10	14	7	9	171
150-160	4	11	7	9	20	9	12	7	5	11	2	9	106
160-170	2	4	11	5	8	6	5	3	2	3	3	5	57
170-180	0	4	5	9	7	6	11	5	1	8	6	5	67
180-190	0	2	3	3	7	0	11	6	2	4	6	2	46
190-200	1	1	3	5	9	1	2	5	1	3	2	2	35
200-	2	1	5	12	22	10	13	9	2	4	3	7	90
Total	246	255	229	261	572	455	1,248	700	197	383	452	375	5,373
Total Weight (kg)	22,700	25,170	24,400	28,550	53,600	34,340	85,460	50,460	19,800	34,870	35,110	35,010	449,470

Table 116.--Numbers of fish by weight classes landed by months at Takao in 1943 (from Nakamura in the Journal of the Formosan Natural History Society, Vol. 34, No. 251)

Weight in kg	Striped marlin												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
10-20	1	1	1	14	4	1	1	0	1	0	0	0	24
20-30	1	0	1	4	20	1	0	2	0	0	0	0	29
30-40	3	6	3	3	48	13	1	0	0	2	0	10	89
40-50	12	17	15	18	59	15	14	4	0	2	2	13	174
50-60	12	14	5	20	46	33	11	4	3	15	4	14	181
60-70	3	6	4	18	21	7	15	2	1	9	6	15	99
70-80	3	2	1	5	5	0	0	0	0	0	0	4	20
80-90	1	1	0	3	4	1	0	1	0	0	0	0	11
90-100	0	1	4	6	0	0	0	0	0	0	0	0	11
100-110	1	0	2	0	0	0	0	0	0	0	0	0	3
110-120	0	0	0	1	0	0	0	0	0	1	0	0	2
120-130	0	0	0	0	0	0	0	0	0	0	0	2	2
Total	37	48	32	82	213	71	42	13	5	32	12	58	645
Total weight (kg)	1,929	2,482	1,677	4,126	10,072	3,419.2	1,757	660.6	2,419.6	2,040.6	611.7	4,227.4	35,422.1

For comparison, in the waters south of the Ogasawara Islands the highest catch rate appeared in August, 1 month later than at Takao. However, it is probably safe to consider that in the sea area centered around 20° N. the density of distribution of black marlin reaches its height around July and August.

Records of the weight of the fish taken are lacking for other sea areas so we do not know the body weight composition of the catch, but at Takao there was a conspicuous difference in the weight composition as between the fish taken in the summer and those taken in the winter. Fish caught in the summer were generally small, with the mode appearing at 40 to 50 kilograms while in November-December it appeared at 60 to 70 kilograms and in January at 80 to 90 kilograms. The weight composition of the fish taken from March to September showed two modes, one at 40 to 60 kilograms and one at 100 to 140 kilograms, (see Nakamura, Journal of the Formosan Natural History Society, Vol. 34).

Table 116 shows fishing conditions at Takao by months for striped marlin. The data are from the same source as those in table 115.

The number of fish taken was not very great, but the largest number appeared in May with the low of the year in September and a second peak appearing in December. This may be compared with the area south of the Ogasawara Islands, where the peak catch rate appeared in May. Thus, although there are points of disagreement between the rises and falls in the catch rate and the increase and decrease in the number of fish landed in each month at Takao, the peak months are the same in both cases and we can probably consider that, just as in the case of the black marlin, dense schools appear at the same season on approximately the same latitudes without regard to longitude.

In the following figures the adjacent area on the north between 25° and 30° N. has been divided into three sections of 140° to 150° E., 130° to 140° E., 120° to 130° E. and the fishing conditions by months have been shown for each of the sections.

As the figure shows black marlin are scarce in the area of 25° to 30° N., 140° to 150° E., but they are somewhat more abundant from April to August. There is an extremely conspicuous peak in the striped marlin catch rate in May with a value of slightly less than 4.0. Thereafter the catch rate falls off steeply and from August to October hardly any fish are taken. In November there is again a fairly conspicuous peak. For all the spearfishes as a whole there is a third peak in February, but this is formed principally of broadbill.

Comparing this with the area south of the Ogasawaras, which adjoins this area on the south (fig. 34), there is a peak in March which does not appear in this sea area but otherwise although there are differences in the numerical values for the catch rates, there is good agreement in the trend of increase and decrease in the striped marlin catch rates and we see no such conspicuous seasonal lag as was found in the case of the yellowfin. The black marlin catch rate curve in this sea area is quite irregular, and its agreement with the curve for the area south of the Ogasawaras is not as striking as it was in case of the striped marlin.

Fishing conditions in the Nankai sea area, 25° to 30° N., 130° to 140° E., are shown in figure 36. A thorough comparison is impossible because of deficiencies in the data, but the black marlin catch rate curve appears to be quite conspicuously different from those for the sea area east of the Izu and Ogasawara islands. In this region there is a fairly high catch rate in January, decreasing thereafter gradually to March and with almost no catch in April, followed by a second increase forming a rather conspicuous peak in June. For the striped marlin there is a conspicuous peak in May and a fairly high catch rate in June, but in July they decrease rapidly. The peak which was seen in the area east of the Izu and Ogasawara Islands in November does not seem to appear here. In the Hyūga Nada region, which adjoins this sea area to the north, striped marlin are abundant around April to June, and quite a few are taken by the harpoon fishery.

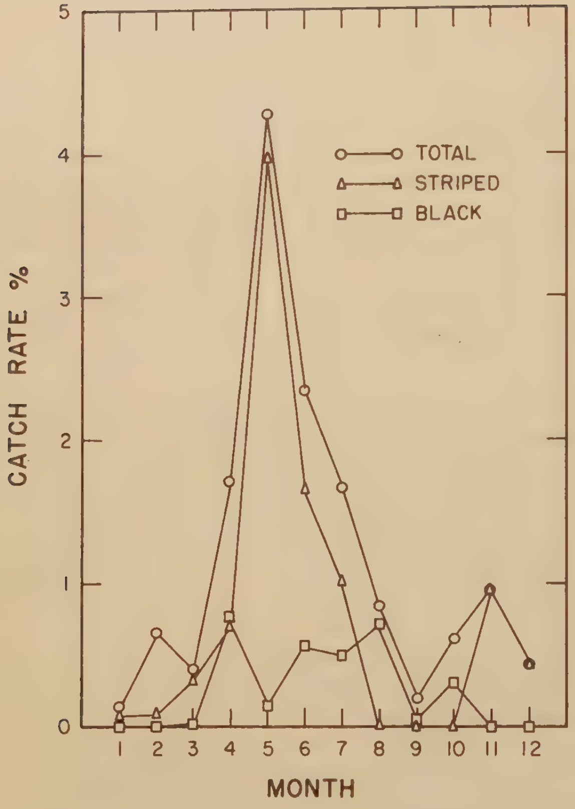


Figure 35.--Spearfish fishing conditions by months (25° to 30° N., 140° to 150° E.)

Shifting farther to the westward, fishing conditions in the waters around the Ryūkyū Islands are shown in figure 37. As the figure shows the pattern of increase and decrease in black marlin catch rates more closely resembles that of the sea area to the east of the Izu and Ogasawara islands than it does that of the Nankai sea area, although there is a lag of about 1 month.

The striped marlin catch rate rises sharply from April on and reaches its high of the year in July. After August it drops off steeply and forms a low in October, after which a fairly conspicuous peak is formed in November. This pattern resembles that for the sea area east of the Izu and Ogasawara islands. In December it again goes down and the second peak of the year is formed in January and February. In the area east of the Ogasawara Islands a peak appears for the spearfishes as a whole in February, but it is formed by broadbill swordfish and differs entirely in character from the January-February peak in this sea area.

As was stated above, the season of the highest catch rates in this sea area is about 2 months later than that in other areas in the same latitude. Furthermore, the period during which the catch rate is over 1.0 extends about half of the year from May to September, a situation which differs markedly from other areas of the same latitude.

The form of the striped marlin catch rate curve described above very closely resembles the increases and decreases in the number of black marlin taken each month in Formosa (table 115). As was stated at the beginning of the chapter, until recent years the spearfishes were not thoroughly classified and it is known that in some cases both the black marlin and the white marlin were recorded as striped marlin, so there is a suspicion that this may be such a case and that other spearfishes may have been recorded as striped marlin. In recent years, particularly, boats based at Kushikino in Kagoshima have been taking a rather large number of black marlin around July to September, and this makes the suspicion all the stronger. At any rate, if we construct a curve of catch rates on the basis of data from past surveys we get the results shown in the foregoing figure.

According to what has been said, the season in which the highest catch rates appear in the vicinity of 20° to 30° N. is everywhere about the same, although there are differences between areas in the numerical values of the catch rates. This is believed to show that the movements of the schools have no important relationship to longitude but that they move rapidly and simultaneously, chiefly in a north-south direction. In other words, this indicates the difficulty of postulating the existence of definite paths of migration. It appears that only the waters

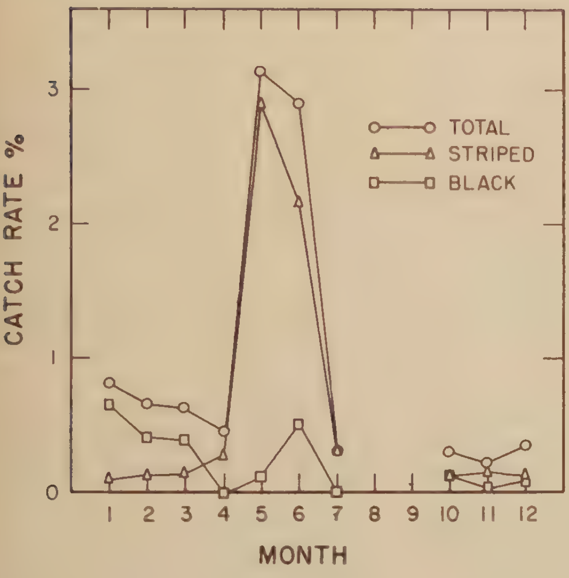


Figure 36.--Spearfish fishing conditions by months (25° to 30° N., 130° to 140° E.)

around the Okinawan archipelago differ somewhat in the character of the schools and of the fishing grounds, but the discussion of these relationships must wait upon more thorough researches to be carried out in the future.

North of 30° N. latitude the catch of striped marlin drops off sharply but off northeastern Japan they are rather numerous from July to September and, as figure 31 shows, there is a blunt peak in the catch rate curve in the vicinity of 36° to 38° N.

As was shown in figure 31, the catch rates for broadbill gradually increase beginning at about 20° N., and around 30° N. they make up more than half of the spearfish catch. As was stated in the chapter on fishing grounds, the areas of high density of occurrence are generally west of 160° E. and they decrease in abundance east of this longitude. The center of the fishing grounds is approximately at the same location as the central fishing grounds shown in the case of the albacore, and the movements of the fishing with the seasons generally resemble those of the albacore. The most important fishing season is almost entirely limited to the winter half of the year. Charts VI, f to k show the movements of these fishing grounds from October to March.

In the chart for October (f) the areas of fishing grounds of dense occurrence appear at 40° to 42° N., 149° to 154° E., although a thoroughgoing comparison is impossible because of the lack of data around the peripheral areas. Some areas of fairly high catch rates are also seen to the southeastward in the vicinity of 36° to 39° N., 155° to 156° E. Elsewhere there are scattered areas of fairly high catch rates off Iwate Prefecture, in the southern Izu Islands, southeast of Amami Ōshima, and east of Formosa.

In the chart for November (g) the fishing grounds have become conspicuously extended, and catch rates of more than 0.5 are indicated for the area from 41° to 31° N., 144° to 156° E. Comparing this with the situation in October, the grounds of dense concentration have extended to the west and south. There are no data for the waters around the Izu Islands, so no comparison can be made with October. In the Okinawa region the areas of high catch rates have shifted to the southwestward and appear off to the east and south of the main island of Okinawa. The fishing grounds to the east of Formosa appear at the same positions as in October, but the catch rates appear to have improved somewhat. Compared with the chart of the distribution of albacore catch rates for November, the broadbill are shown to be abundant somewhat more to the north and east.

In the chart for December (h) the center of distribution is farther south than in November in the vicinity of 55° N. and areas with catch rates of over 1.0 are recorded from the range of 35° to 40° N., 150° to 152° E. Compared with November, the fishing grounds are extended a good deal to the southwest and areas with rather high catch rates appear from off Bōsō

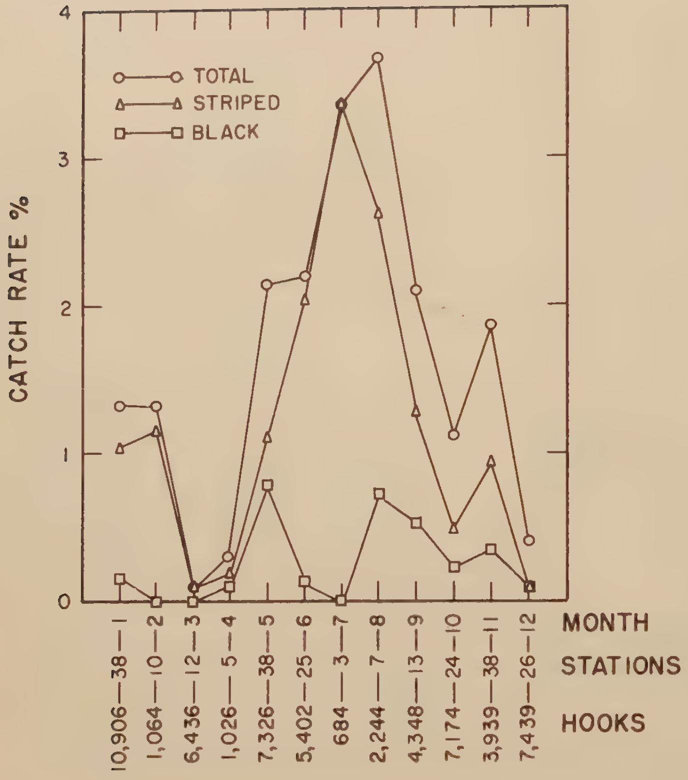


Figure 37.--Spearfish fishing conditions by months (25° to 30° N., 120° to 130° E.)

to the waters around the Izu Islands. Farther to the west there are fishing grounds with catch rates of over 1.0 about 300 miles south of Ashizuri Misaki and northwest of the main island of Okinawa, while fishing is quite active all over the sea area between them from 27° to 28° N., 128° to 133° E. Fishing is poor in the waters east of Formosa.

Compared with the albacore grounds centered around 150° E. in December, there is general agreement but the western tip of the broadbill grounds extends farther west than do the albacore grounds. At this season dense schools of albacore believed to be of a different stock appear south of Shionomisaki, but there are no broadbill there, although as previously stated fishing grounds with dense concentrations appear in the waters around Okinawa.

In the chart for January (i) the fishing grounds have moved farther south and are centered along 151° E., with the heart of the fishing grounds in the area of 32° to 38° N. The schools in the waters around the Izu Islands are separated from those which are broadly distributed to the eastward, and there appears to be a densely concentrated group of fish in the comparatively narrow area at 30° to 34° N., 134° to 137° E. Outstanding fishing grounds have disappeared from west of the Izu Islands, with the sole exception of some areas with rather high catch rates around the Miyako archipelago. Areas with catch rates of over 1.0 are to be seen in the vicinity of 29° to 50° N., 161° to 162° E., but there are few data from that region so it is difficult to determine whether these are merely fortuitous or actually good fishing grounds.

At the same season the center of distribution for albacore is, with the exception of the central part of the Pacific, at 29° to 33° N., 143° to 148° E. Consequently it can be seen that the center of distribution of the albacore is somewhat more to the south and west, however, the albacore catch rates in the waters around the Izu Islands are not very high. The albacore grounds in the Kinan sea area are greatly extended as compared with December.

In the chart for February (j) the center of the fishing grounds has shifted even farther to the southwest to the waters east of the line of the Izu and Ogasawara islands in the vicinity of 27° to 32° N., 140° to 145° E. The grounds of particularly high catch rates are in waters close to the line of islands. There are no fishing grounds with high catch rates farther to the westward in the Satsunan region except for a few areas of rather high catch rates east of Amami Ōshima. The grounds east of Formosa, which had disappeared since December, come back with some catch rates of over 0.5.

The center of albacore distribution in February is 1° or 2° east of that of the broadbill, but the pattern of distribution is very similar. The albacore grounds in the Kinan sea area are more extensive than in January and the fishing appears to be better.

In the chart for March (k) the center of distribution has moved somewhat north of its position in February and is within the range of 30° to 34° N., 140° to 147° E. To the southeast and separate from this center there is an area of high density of occurrence in the vicinity of 30° N. 152° E. It is impossible to determine whether these two areas are connected or whether they are completely separate because of the paucity of data. In the waters west of the Izu Islands, including those around the Ryūkyūs and Formosa, no areas of high catch rates are to be seen at all.

The center of distribution of albacore in March appears to be somewhat to the south of that of the broadbill, and in general the density of occurrence appears to have decreased. The albacore grounds in the Kinan sea area have moved somewhat to the south.

From the foregoing, it appears that the center of distribution of the broadbill, in a very general view, is in the vicinity of 140° to 155° E., and that the schools which in October are in the vicinity of 42° N. gradually move south with the passage of time. This southward movement is accompanied by an extension of the fishing grounds to the east and west, and it appears that from January on part of the schools remain in the waters east of the Izu and Ogasawara islands. It is unknown whether or not they cross to the westward of this line of islands, but judging from the distribution of catch rates it appears that they do not and the vicinity of 140° E. is considered the apparent boundary of their distribution and migrations. As has already been stated, at some seasons areas of a fairly dense distribution appear in the waters around Formosa and the Ryūkyū Islands, but the relationships between the schools appearing in this region and those which occur to the east of the line of the Izu and Ogasawara archipelagoes are completely unknown at present.

Broadbill do appear in the tropical sea areas to the south of the sub tropical line of convergence, but there are no fishing grounds on which concentrated catches of this species are made. However, there are many immature fish in this region and larval and juvenile forms appear to occur there, in many cases forming part of the food of other tunas and spearfishes. This phenomenon is not as yet well understood, but it probably gives an important clue to the area of reproduction of the broadbill and should be given serious consideration from the point of view of ecology and population studies. In any case, it is worthy of careful note that the fishing grounds of the broadbill swordfish appear to be limited on the south by the subtropical convergence, on the west by the line of the Izu and Ogasawara archipelagoes, and on the east by approximately 160° E.

In the foregoing we have attempted to consider the patterns of distribution and migration of each species based on the catch rates, and on this basis there appear to be for each species two types of patterns, the boundaries between which appear to be geographically the subtropical convergence, the area of contact of the Equatorial Countercurrent and the North Equatorial Current, and the line of the Izu and Ogasawara archipelagoes.

One of these two types of patterns is represented by the striped marlin, which extend over the whole area in the vicinity of 20° to 30° N., and the black tuna, which occur from the vicinity of Luzon to the area of the Kuroshio. In this type dense schools appear over a broad expanse of ocean in an extremely short period of time and then after a very short time disappear again, so that it is extraordinarily difficult to follow the paths of their migrations. For instance, the catch rate curves for striped marlin all show the highest peak of the year in May in the waters of the Marianas in the vicinity of 20° N., in Formosan waters, in the waters of the Izu

Islands around 30° N., in the Kinan sea area, and farther north in the Hyūga Nada. Because they make their appearance within a short time and then move away somewhere within a short time, the peak in the catch rate at this season is extraordinarily sharp.

In the second type of pattern the schools gradually become more concentrated in a comparatively limited area and the schools so formed move and migrate comparatively slowly. Examples of this type are the spearfishes which appear around Formosa in the winter, the black tuna around Tanegashima, the albacore of the Kinan sea area, the broadbill of the northeastern sea area, and the albacore of the central North Pacific. In this type the center of the fishing grounds does not make any very violent shifts, and the catch rates gradually increase with the passage of time and then gradually decline. Consequently in this type it seems as if the schools congregate successively in one sea area after another, and the center of the grounds moves comparatively slowly with the passage of time. As a result, it is easier to follow the paths of migration of the schools in this case than in the former type, and the slopes of the seasonal catch rate curves in a given area are comparatively gentle.

It is impossible at present to give a full explanation of the relationships between the ecological significance of these two types and oceanographic conditions, however, on the basis of what data we have it appears that the former is related to spawning while the latter is more deeply related to food hunting. Accordingly, the former is to be thought of as the spawning season type of migration and the latter as the food-seeking type of migration. However, in many cases it is difficult to draw the line clearly between these two types and opinions will differ on where to establish the criterion. Furthermore, more data are necessary in order to establish clearly whether or not these two types actually exist, and it goes without saying that we can arrive at no conclusion without further research.

Thus we can under the present conditions do nothing concrete about the biological and oceanographical essentials and their theoretical analysis, but from the point of view of the commercial fishery it can be imagined that these two types will have a rather important significance. It may also be thought that they would be highly significant from the point of view of population studies, and we feel keenly the necessity for tagging studies to trace the paths of migration, morphometric studies, more complete fish catch statistics, and thorough studies of the spawning and feeding habits of the fish.

VII. Conclusions

1. Data from past surveys covering about 20 years have been gathered and worked up. There are omissions because of the author's inability to obtain some of the past data.

2. An attempt has been made on the basis of these data to clarify the character of the tuna longlining grounds of the eastern Indian Ocean and the western Pacific.

3. A description in brief has been given of the existing tuna and spearfish fisheries and a discussion has been made of the character of the tuna fishery.

4. Tuna grounds hitherto had been discussed in terms of total catch and number of vessels operating, but this method leaves the relationship between fishing effort and catch unclarified. In order to explain this relationship the number of hooks has been taken as the unit of fishing effort. The number of fish caught per hundred hooks has been called the catch rate. Consequently the fishing grounds discussed in this book are limited to the grounds of the longline fishery.

5. Sea areas have been delimited mainly by longitude and latitude or by topography, the seasonal and geographical variations in fishing conditions have been recorded in terms of catch rates, and the character as fishing grounds of the various sea areas has been discussed.

6. At the same time it has been postulated that the catch rates are proportional to the density of distribution of these fishes and the distributions and migrations of the fishes have been considered on this basis.

7. In this manner some information has been gained, but unfortunately, because of the great unevenness in the seasonal and geographical distribution of the data, it has been impossible to arrive at as satisfying a conclusion as was hoped for at first.

8. However, in some sea areas data are fairly abundant and it can be thought they will have some value and significance as basic information for production plans.

9. When we consider the distribution and migration of these fishes on the basis of their catch rates, the ordinary pattern which we find is for a plot of the curve of catch rates by months in a given sea area to have two peaks and two low points in the year, one pair in the summer and one pair in the winter. The catch rates go from their maximum to their minimum in about half a year. Consequently it is thought that there is a 1-year cycle in the movements of the schools.

10. As was just stated, two peaks in the catch rates in 1 year can be detected, but they appear to differ somewhat in character. It is believed that usually the peak which appears in the summer is made up of so-called "ascending fish" and that appearing in the winter is made up of the so-called "descending fish".

11. These two types of migration appear in some species to be divided into spawning migrations and food-seeking migrations. In the cases which are thought to be of the spawning migration type, dense schools appear over a rather broad sea area in an extremely short period of time and then disappear with equal rapidity so that it is difficult to follow the paths of their migrations. In the cases which are thought to represent food-seeking migrations, the schools appear to congregate gradually in a comparatively limited area, the movements of the schools are comparatively slow, and the paths of migration can be determined quite clearly.

12. Under present conditions the matters discussed in the preceding paragraph are still completely within the realm of hypothesis. They must be clarified in the future by tagging experiments, fish catch statistics, and biological studies, but they are believed to have an important significance both from the point of view of the commercial fishery and from the point of view of population studies.

APPENDED CHARTS OF THE FISHING GROUNDS

(Translator's note: The following charts have been given the same numbers by which they were referred to in the text, however, they have been bound out of numerical order, with the larger charts last, for convenience in making up the book. This inconsistency, although regrettable, is necessitated by a similar inconsistency in the make-up of the original work.)

Chart IIa-e

Albacore catch rate distribution by months for January, February, March, November, and December. The figures inside the 1-degree squares are average catch rates (fish caught per 100 hooks fished per day). The vertical hatching indicates rates of 1.0 to 3.0, oblique hatching 3.0 to 5.0, and cross-hatching over 5.0, however, this code is not used consistently. Squares containing zeros are those in which some fishing was recorded without any catch of albacore.

Chart VIf-k

Distribution of broadbill swordfish catch rates by months for January, February, March, October, November, and December. Squares with average rates of 1.0 or more are shaded.

Chart I

This chart of the combined average catch rates for all species of tuna and spearfish has been omitted from the translation.

Chart III

Distribution of bigeye catch rates. The figures within each 1-degree square are from top to bottom the average catch rate, the total number of hooks fished, and the number of stations fished. The shaded squares are those in which rates greater than 1.0 were recorded.

Chart IV

Distribution of yellowfin catch rates. Dark shaded squares are those with catch rates greater than 5.0, diagonally hatched squares are those with rates of 3.0 to 5.0, and gray shaded squares had rates of 1.0 to 3.0.

Chart V

Distribution of spearfish catch rates, all species combined. The 1-degree squares with catch rates of 1.0 or more are shaded.

CHART IIa

ビンナガ漁場圖（一　月） ALBACORE (JANUARY)

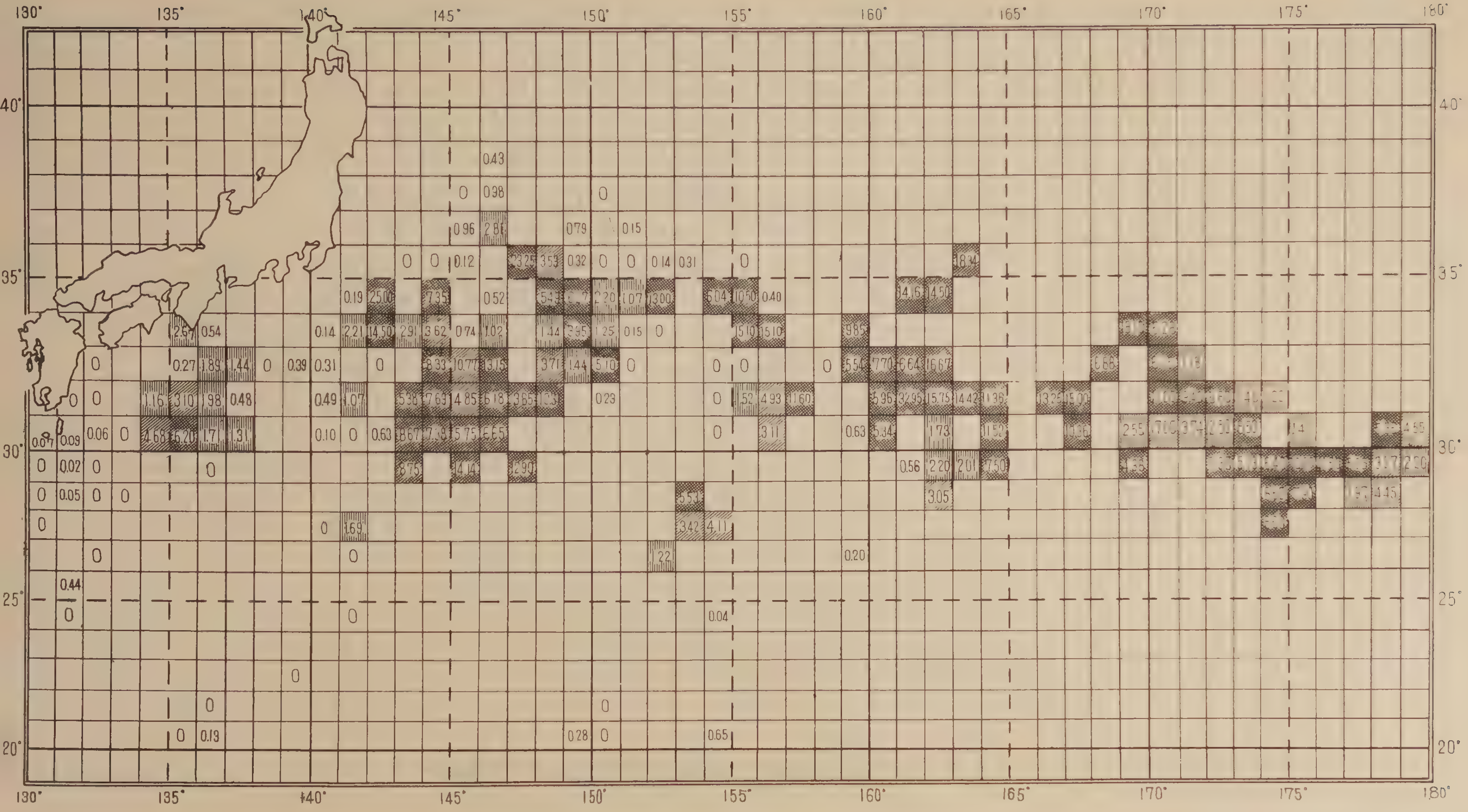

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CHART IIb

ビンナガ漁場圖（二　月）ALBACORE (FEBRUARY)

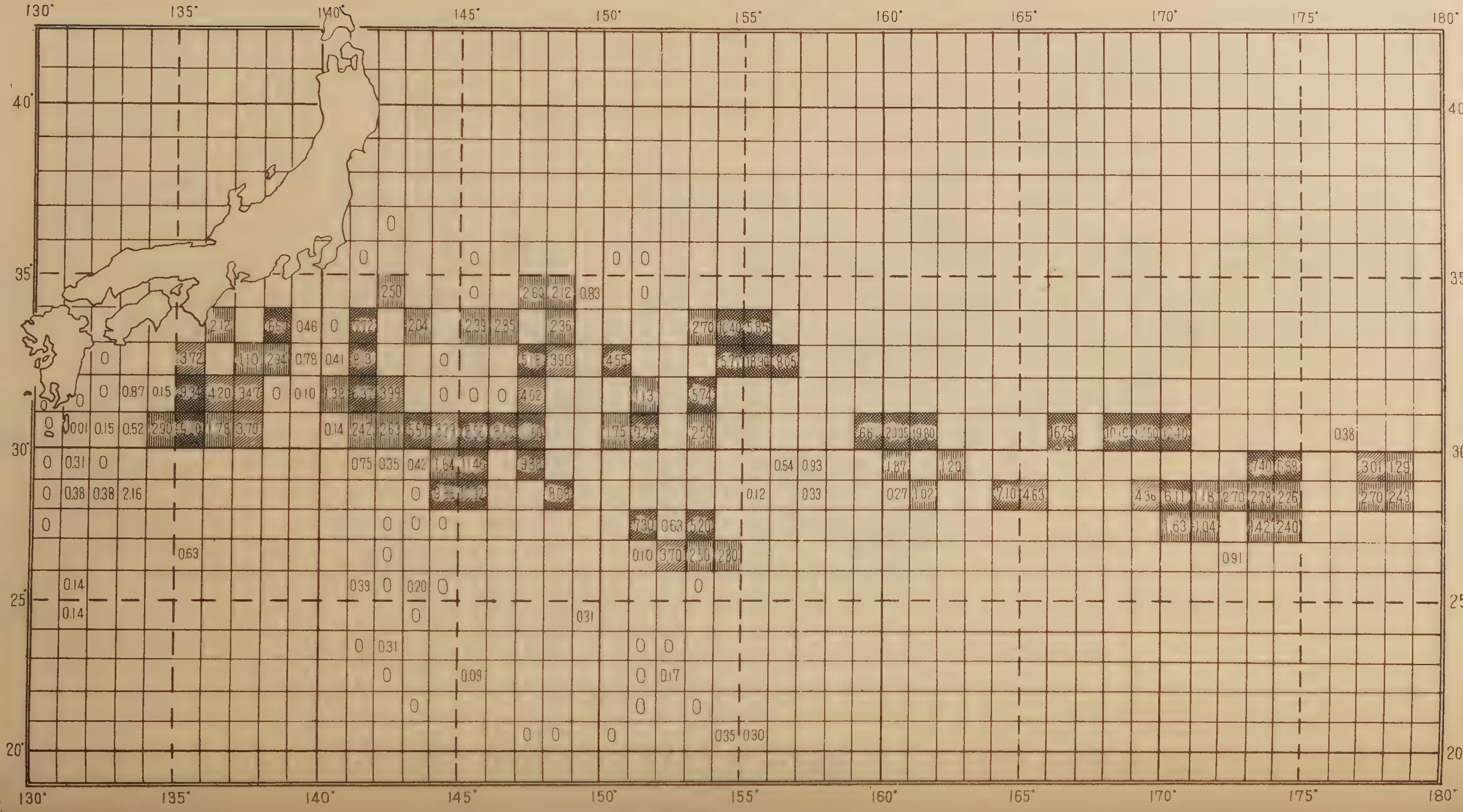
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CHART IIc

ビンナガ漁場圖（三　月）ALBACORE (MARCH)

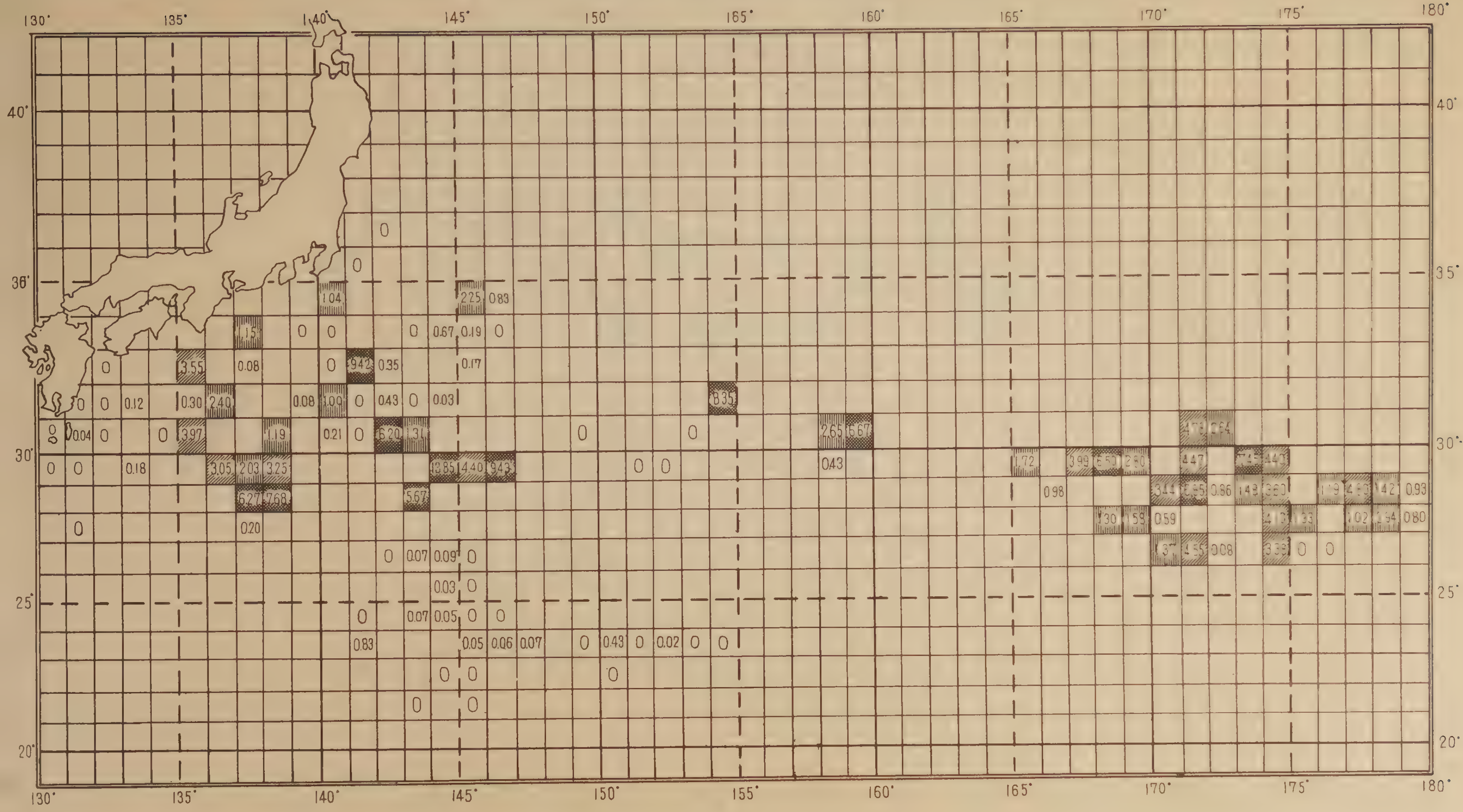
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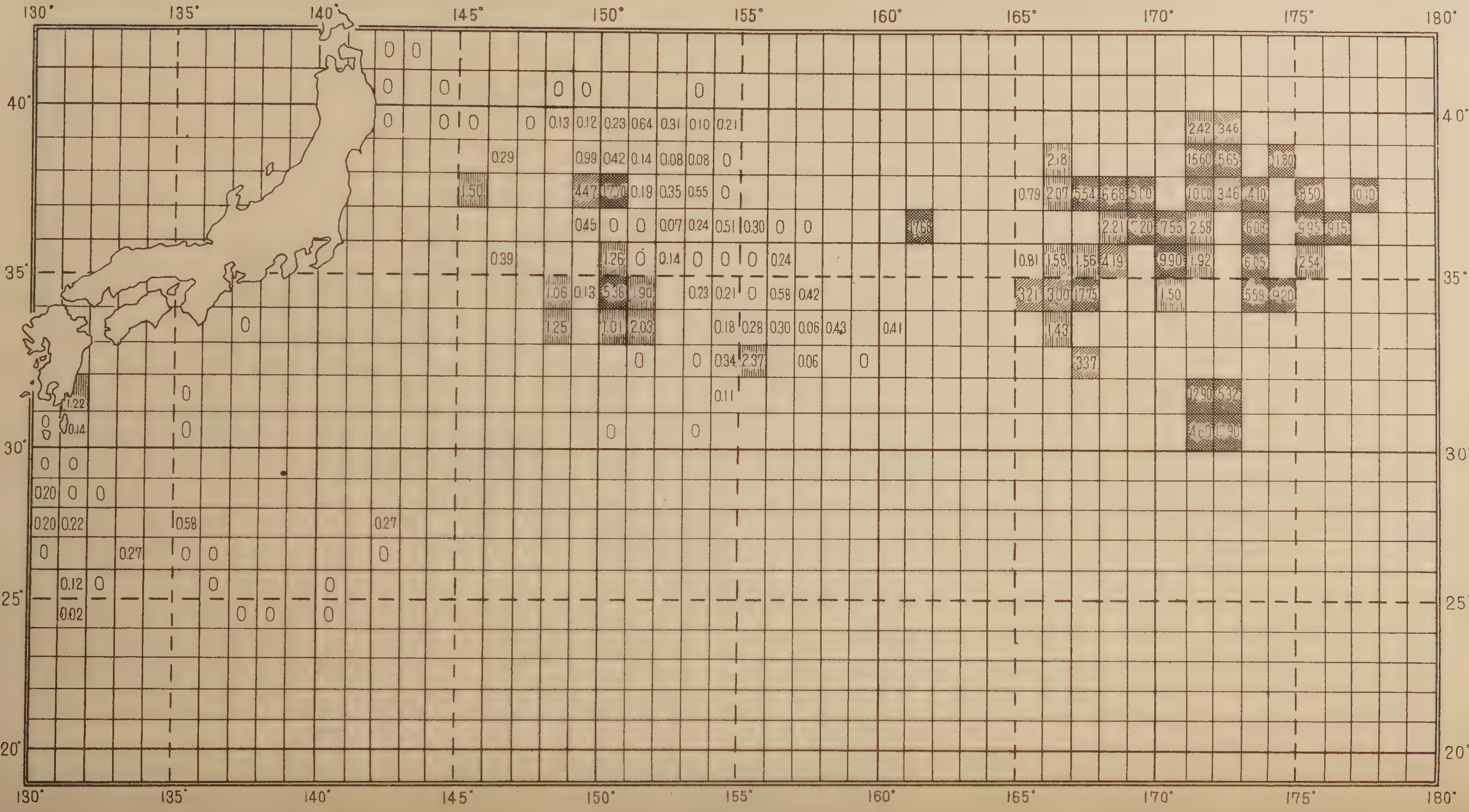
CHART IId

ビンナガ漁場圖（十一月）ALBACORE (NOVEMBER)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ビンナガ漁場圖(十二月) ALBACORE (DECEMBER)

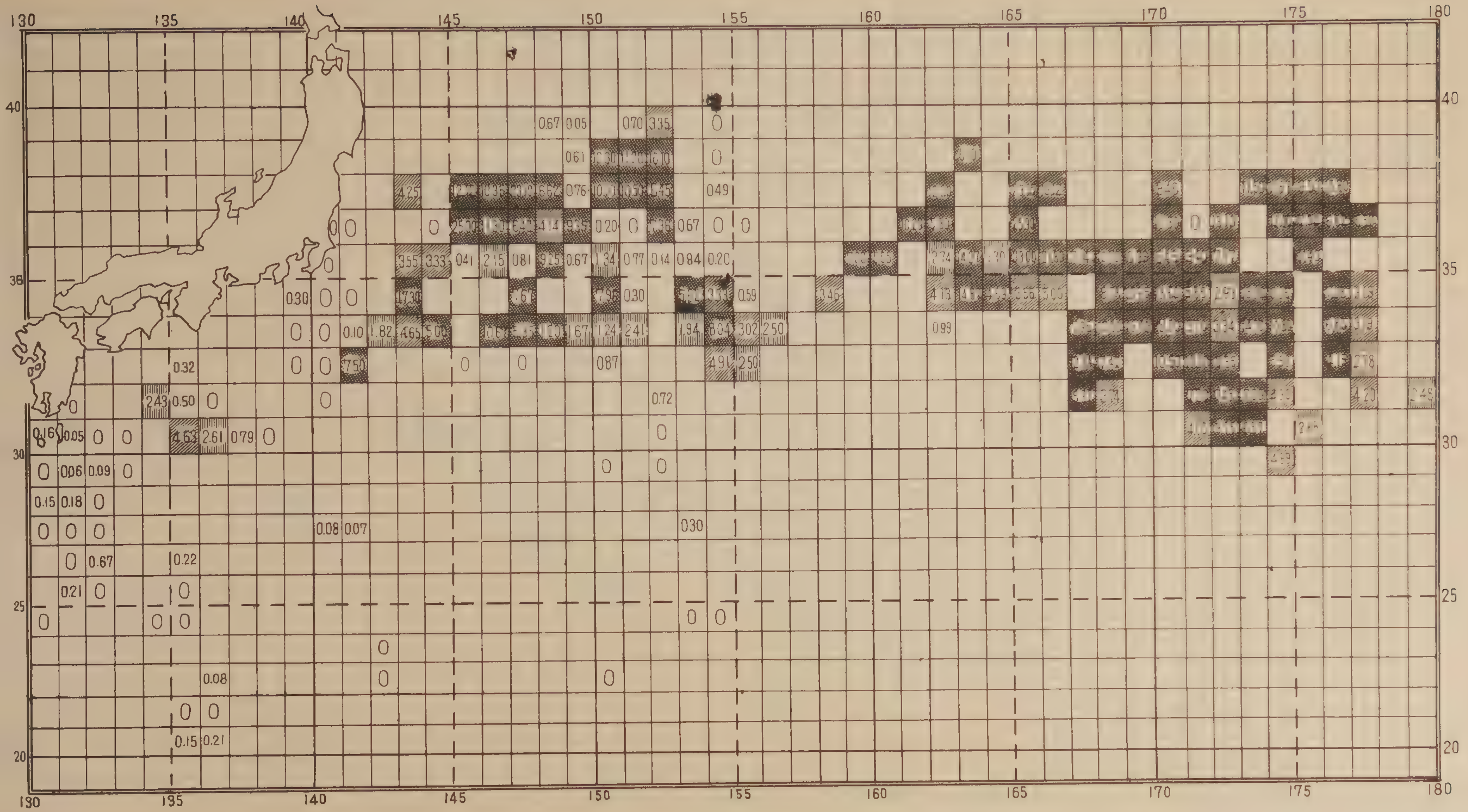
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CHART VIf

メカヂキ

1　月

BROADBILL

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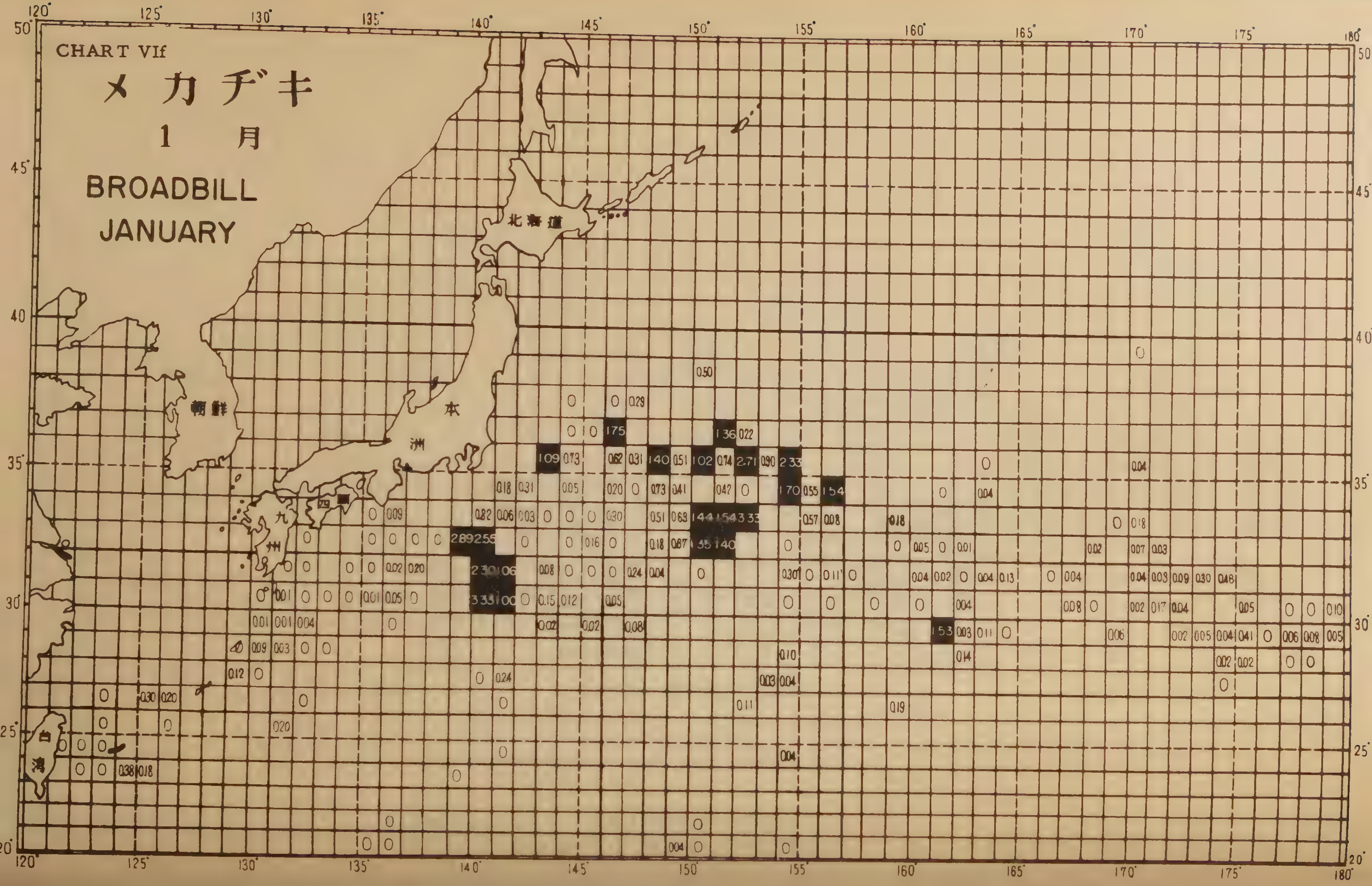
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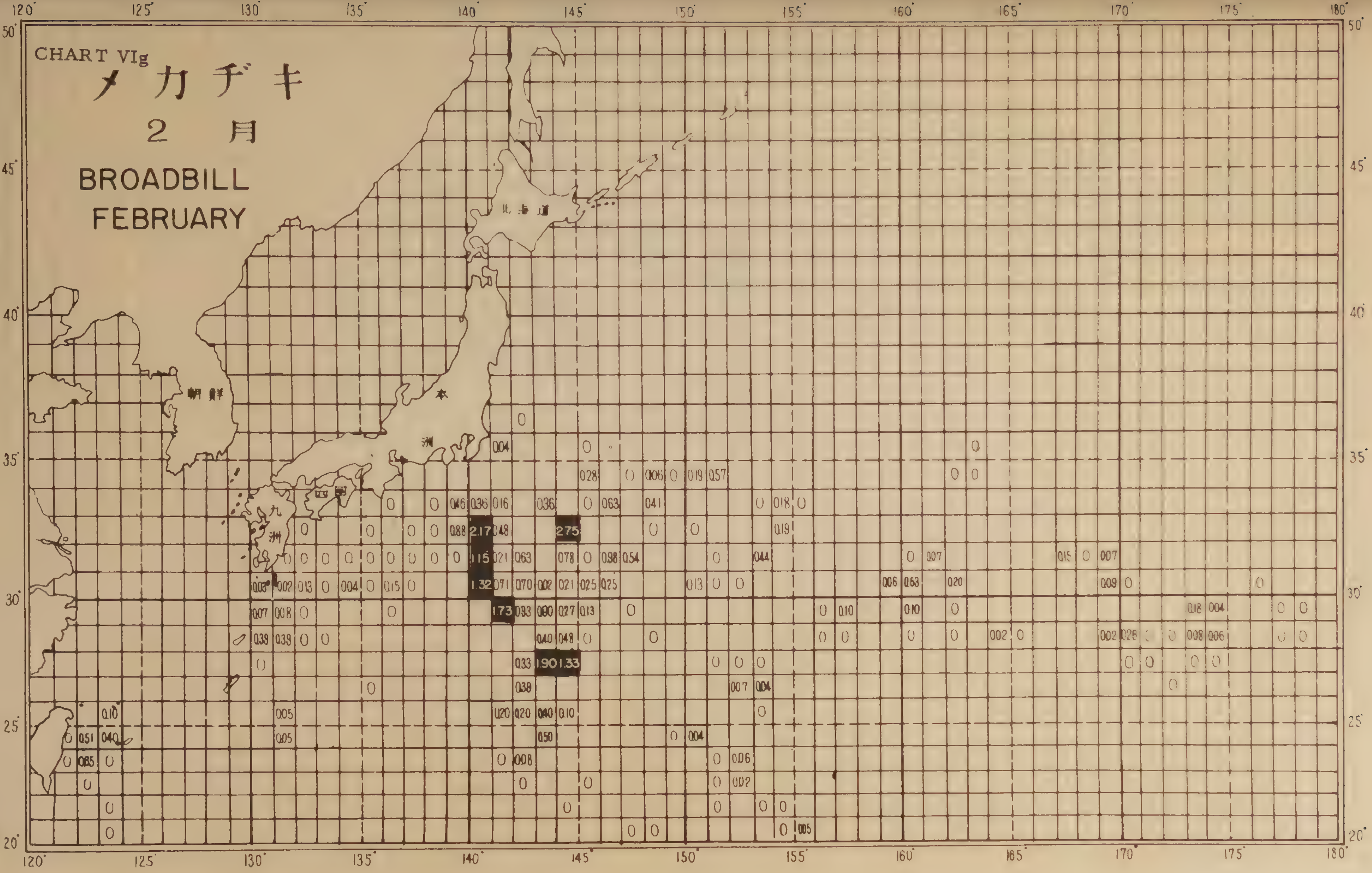

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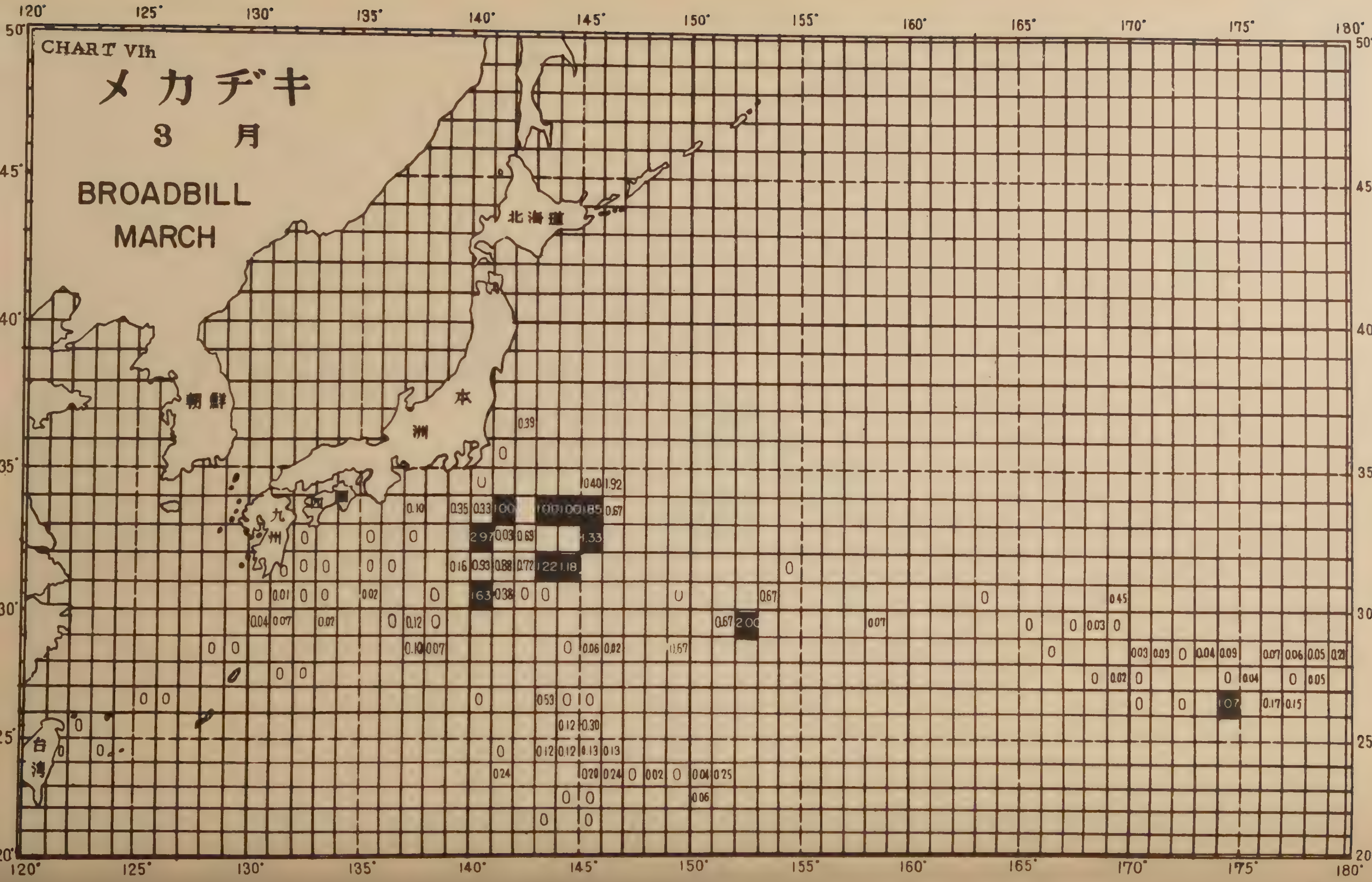
CHART VIh

メカヂキ

3 月

BROADBILL

MARCH



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10 月

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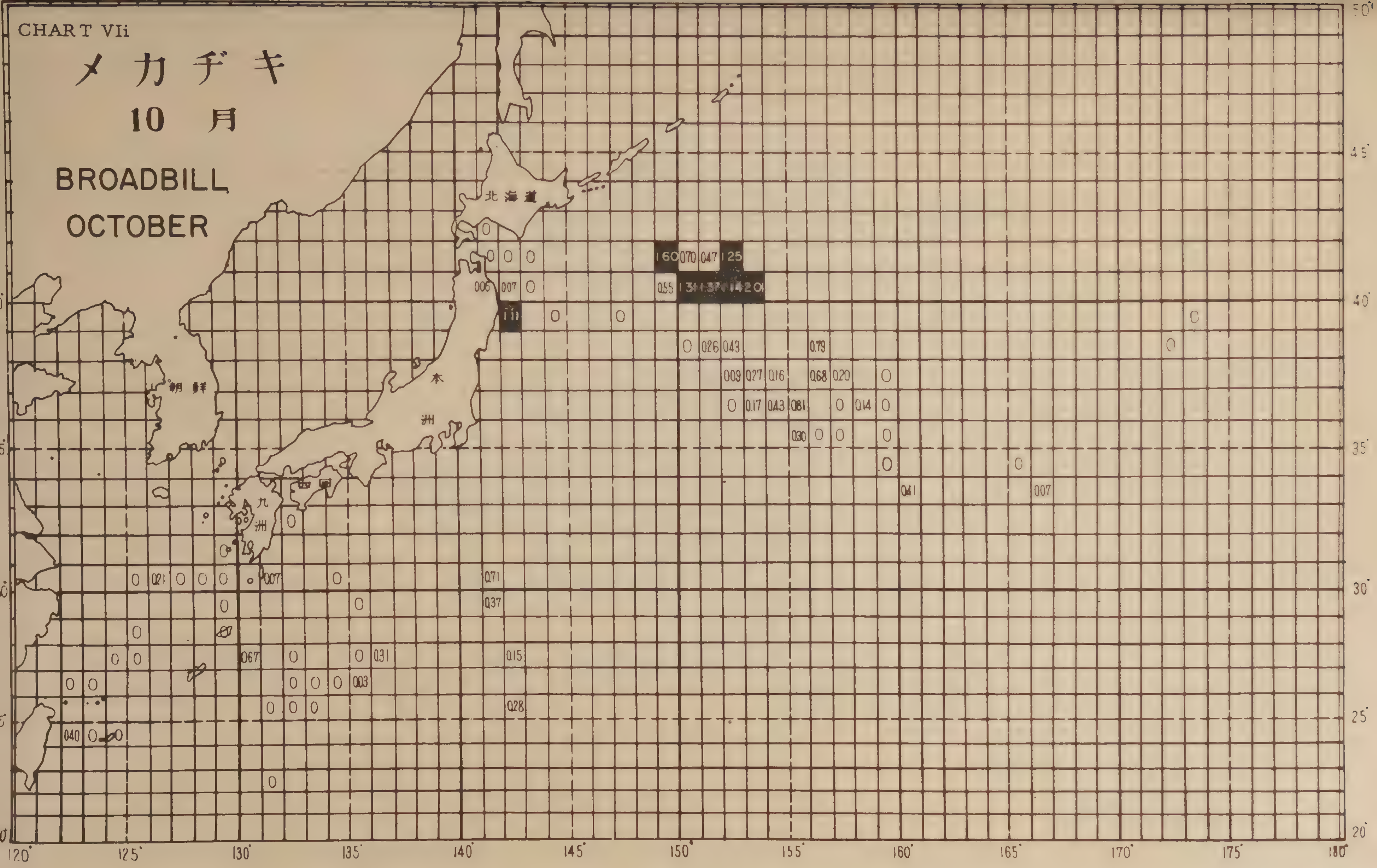
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CHART VIj

メカヂキ

１１月

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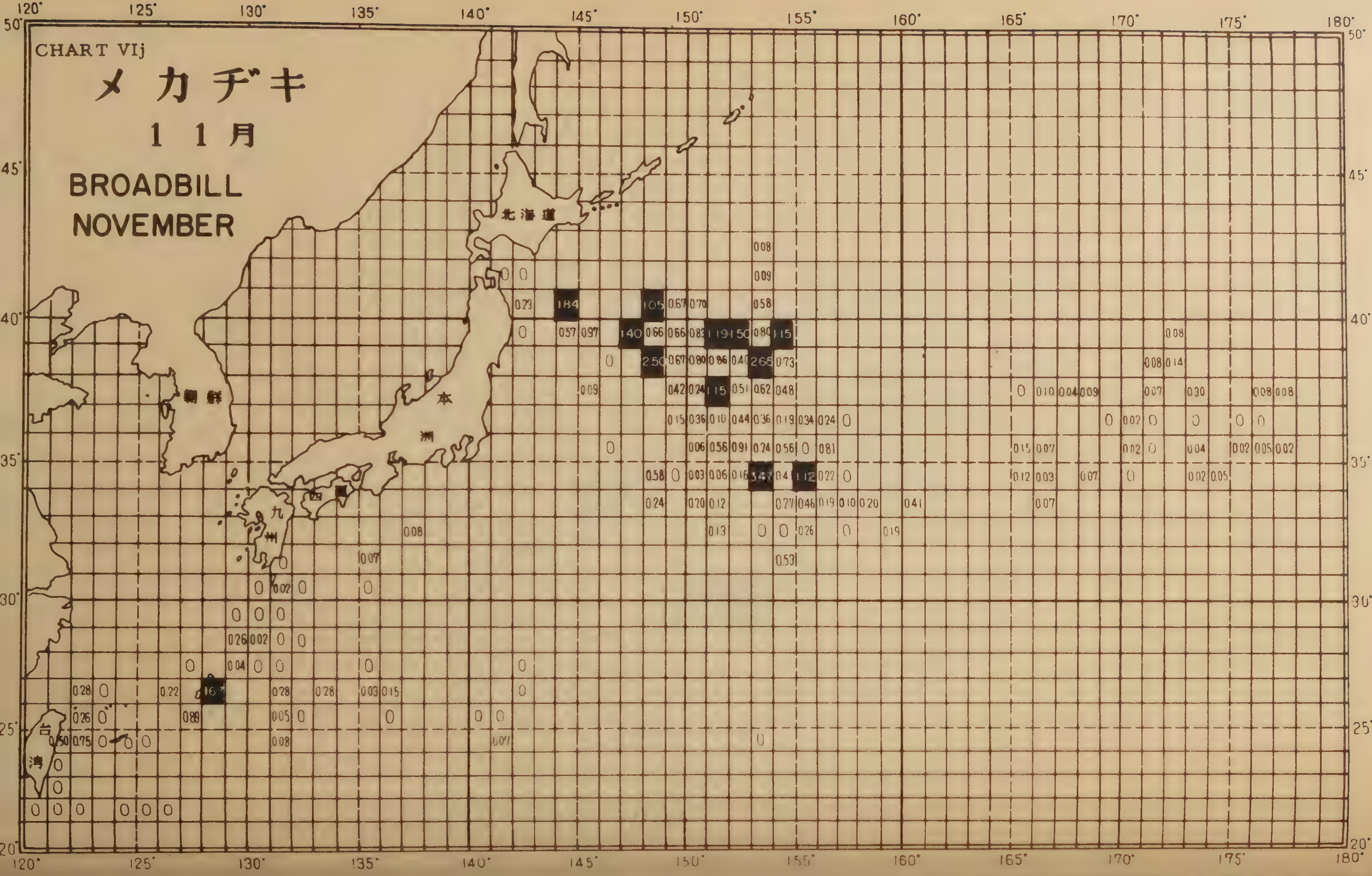
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CHART VIk

メカヂキ

１２月

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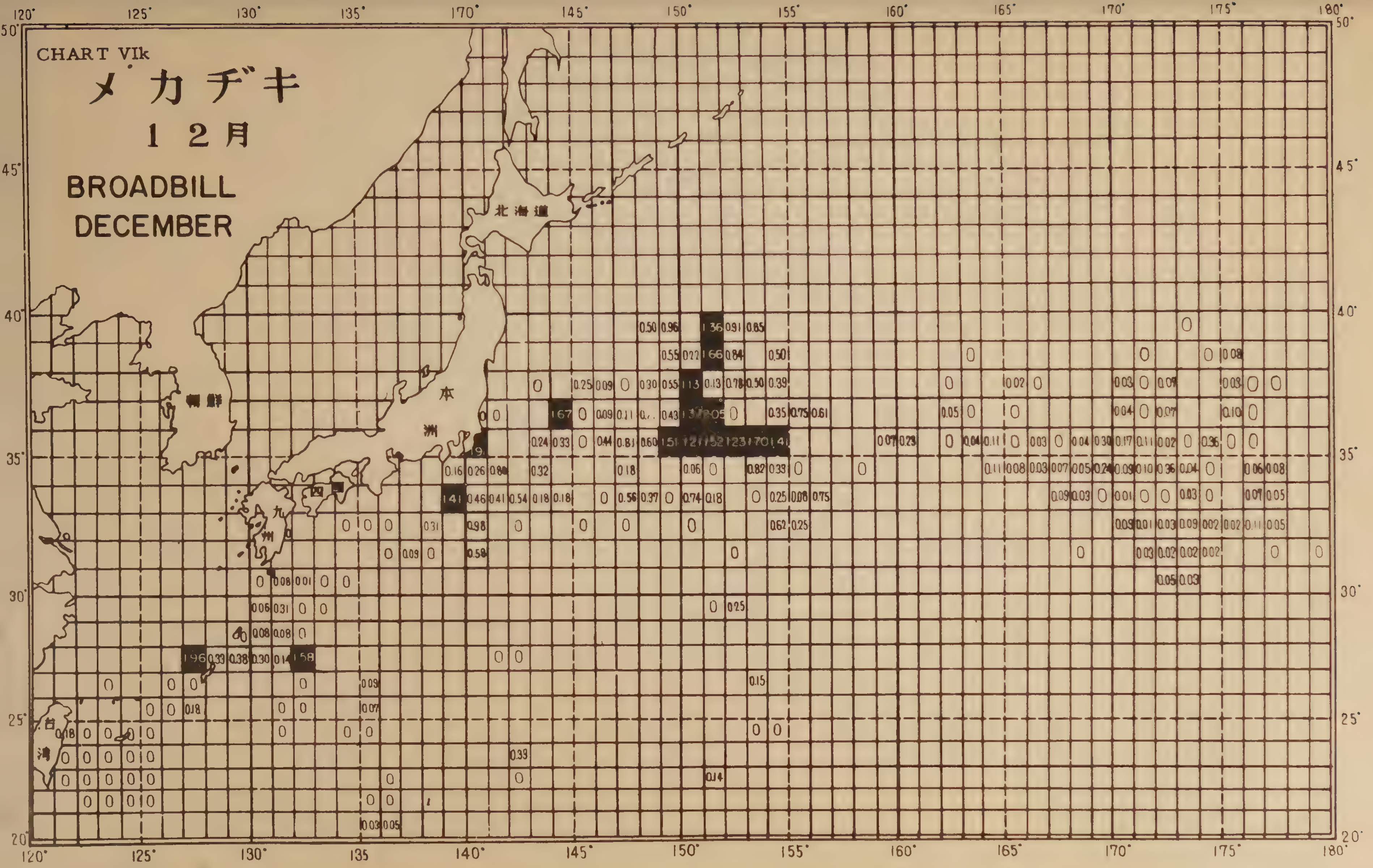

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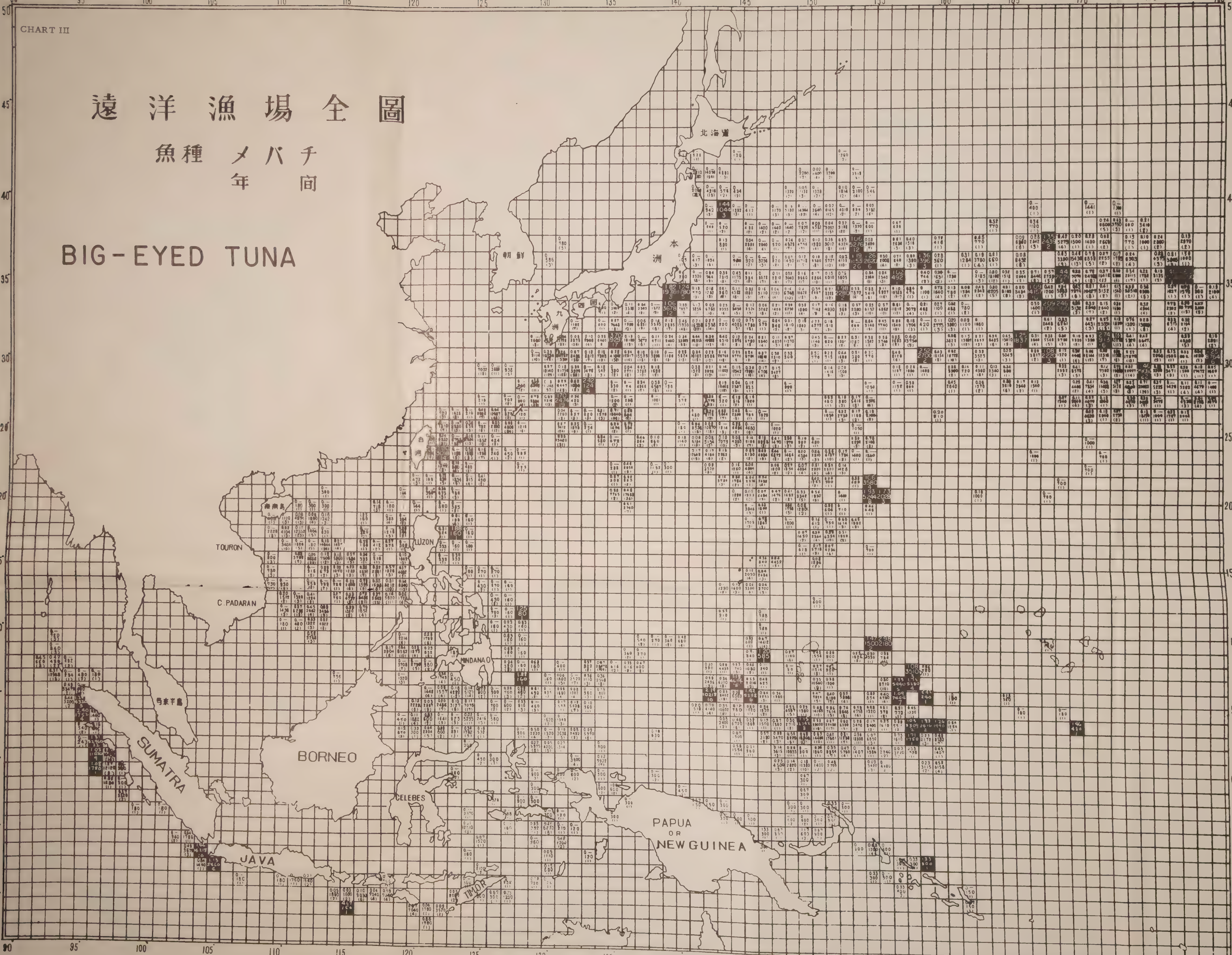
CHART III

遠洋漁場全圖

魚種　メバチ
年　間

BIG-EYED TUNA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台湾
海南島
TOURON
LUZON
C. PADARAN
MINDANAO
馬來半島
SUMATRA
BORNEO
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TIMOR
PAPUA OR NEW GUINEA
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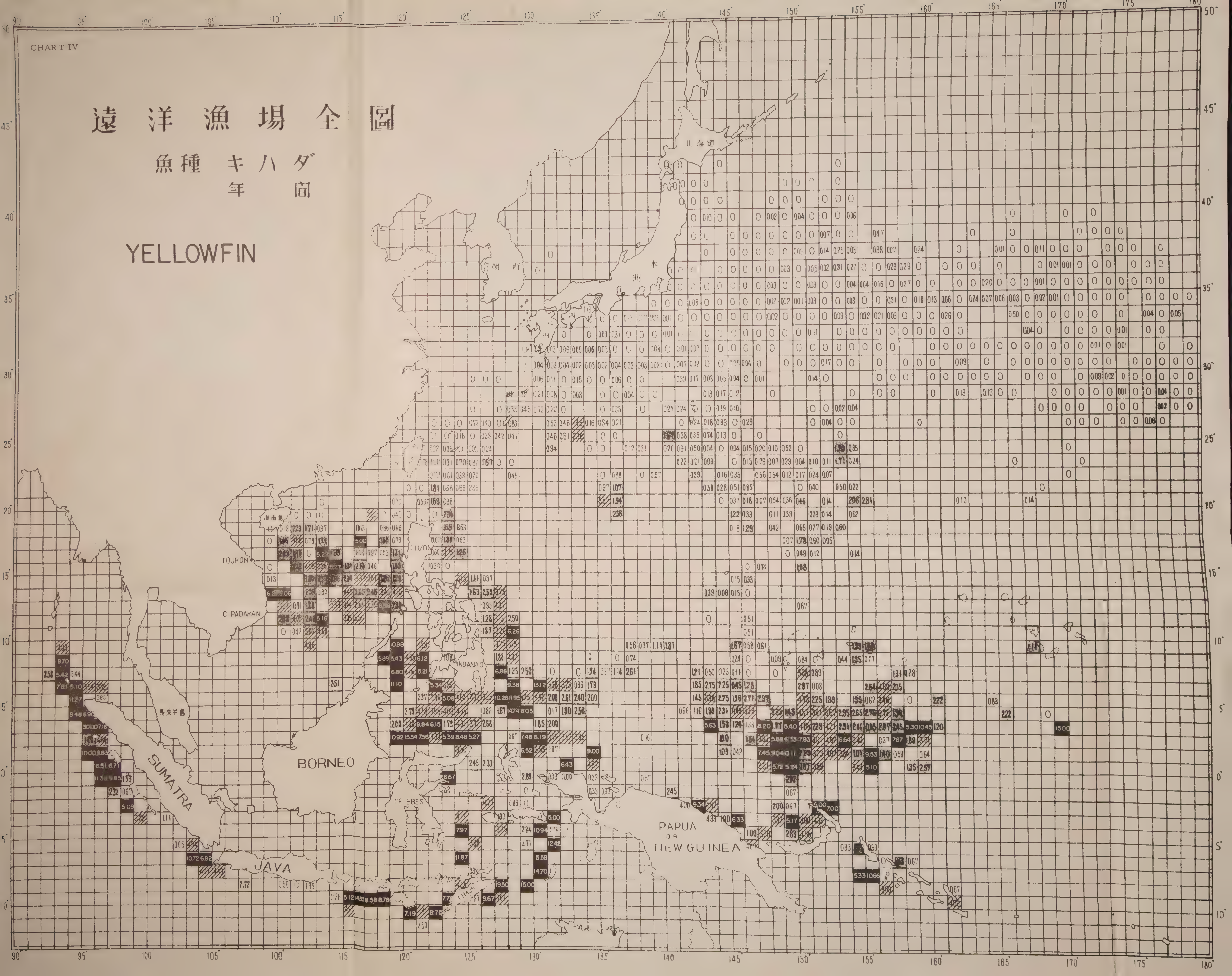
CHART IV

遠洋漁場全圖

魚種 キハダ
年間

YELLOWFIN

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本
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鮮
海南島
TOURON
C. PADARAN
LUZON
MINDANAO
馬來半島
SUMATRA
BORNEO
CELEBES
JAVA
PAPUA
OR
NEW GUINEA
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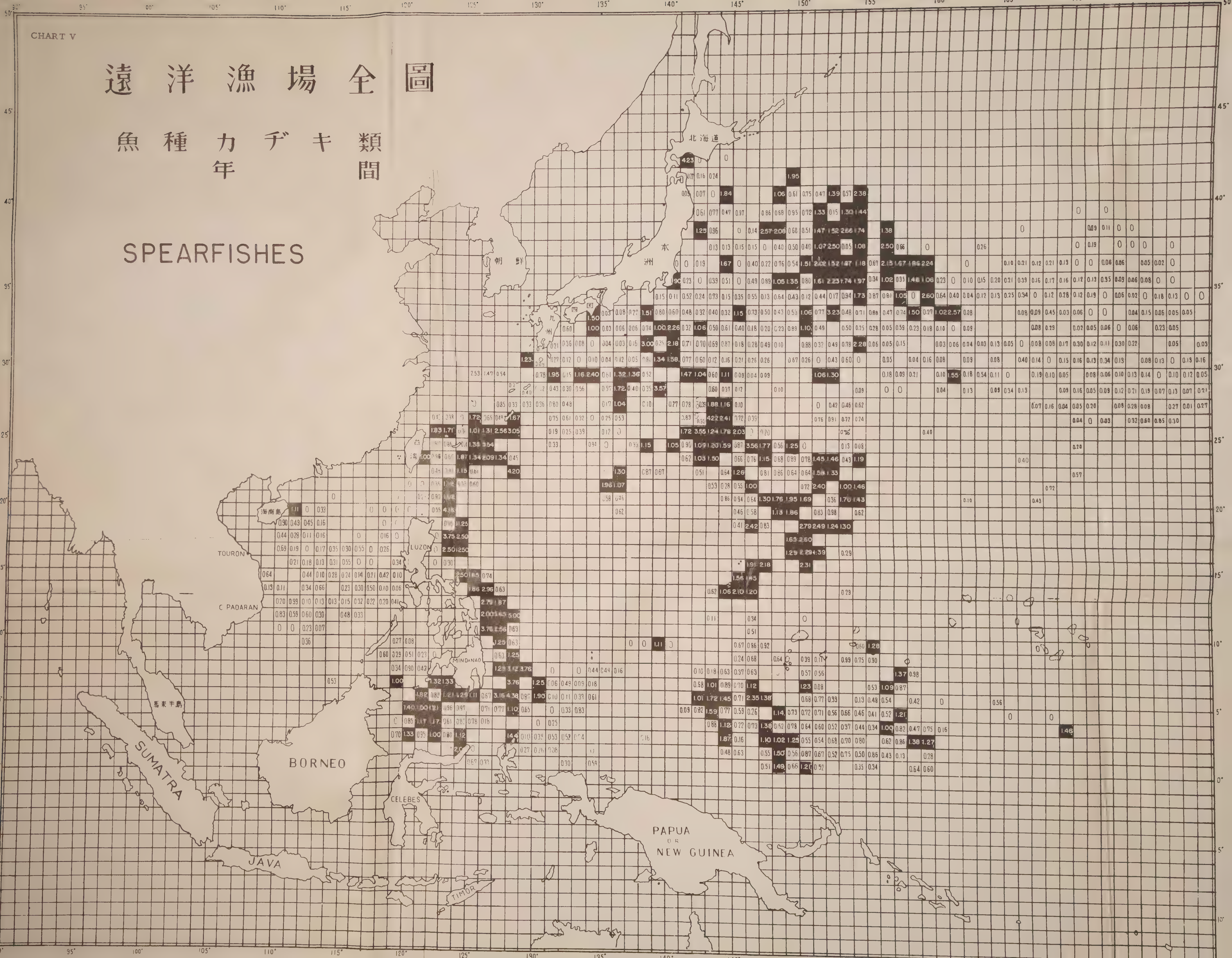
CHART V

遠洋漁場全圖

魚種 カヂキ類
年間

SPEARFISHES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TOURON
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LUZON
MINDANAO
SUMATRA
BORNEO
CELEBES
JAVA
TIMOR
PAPUA
OR
NEW GUINEA
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ANALYSIS OF THE HAWAIIAN LONG-LINE FISHERY, 1948-52

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SUMMARY

1. The long-line method is presently the only means of efficiently catching the osurface resource of tunas and spearfishes in the vicinity of the Hawaiian Islands.

2. The tuna landings have steadily increased following a period of restricted hing during World War II.

3. The species composition of the tuna landings have changed from a predomince of yellowfin to one of big-eyed during the postwar years.

4. There is a marked seasonal variation in abundance among the tunas, with lowfin occurring in greater numbers during the summer and the big-eyed during winter months. There is less variation in seasonal abundance among the spearhes, with the black marlin generally more abundant during the summer months d the striped marlin in the winter.

5. This seasonal variation in species composition is dependent upon the movents and local abundance of the fish. Both of these factors may be influenced by of a number of environmental factors; e.g., sea temperature is frequently beved to be important, however, the available data are too scanty to be conclusive.

6. There is a possibility that the occurrence of yellowfin in greater numbers ring the summer is related to spawning.

7. The possibility also exists that yellowfin are responding to a slightly more ndant food supply during the summer months in island waters.

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8. The average total catch rate (catch per 100 hooks fished per day) is about 3.0, which compares favorably with the Japanese catch in their home waters but falls below their catch in various tropical and subtropical areas.

9. The amount of effort expended by the fleet from year to year did not vary significantly during the years surveyed.

10. There appears to be a seasonal shifting of the more productive fishing grounds. Windward waters are said to be more productive during the winter month

11. Noticeable variations in boat efficiency may be attributed to differences in the productivity among various areas, since certain of the low-catch boats fish exclusively in one area regardless of productivity.

12. The long-line fishery catches yellowfin over 90 pounds in weight, with the bulk of the catch falling between 100 and 160 pounds. The big-eyed are somewhat larger, with the bulk falling roughly between 100 and 200 pounds. Yellowfin averag around 140 and the big-eyed around 160 pounds.

13. The sex ratio among long line-caught yellowfin and big-eyed tuna differs significantly from 50:50 (or 1:1) with males predominating in both species.

14. There is a possibility that yellowfin spend their first year or two at the surface before descending to subsurface levels. This may be a basis for a method of predicting the abundance of subsurface yellowfin a few years in advance.

15. The limited market makes the price especially sensitive to supply and consequently serves to limit fishing intensity.

BACKGROUND

The long-line fishery of Hawaii catches the deep-swimming pelagic tunas and spearfishes in the coastal and offshore waters of the Hawaiian Islands. Having had its beginning in 1917, when a Japanese immigrant introduced the Japanese technique of fishing subsurface levels in waters off Waianae, Oahu, this fishery has rapidly developed into a major source of fish in the Territory; its landings are valued at over a million dollars annually.

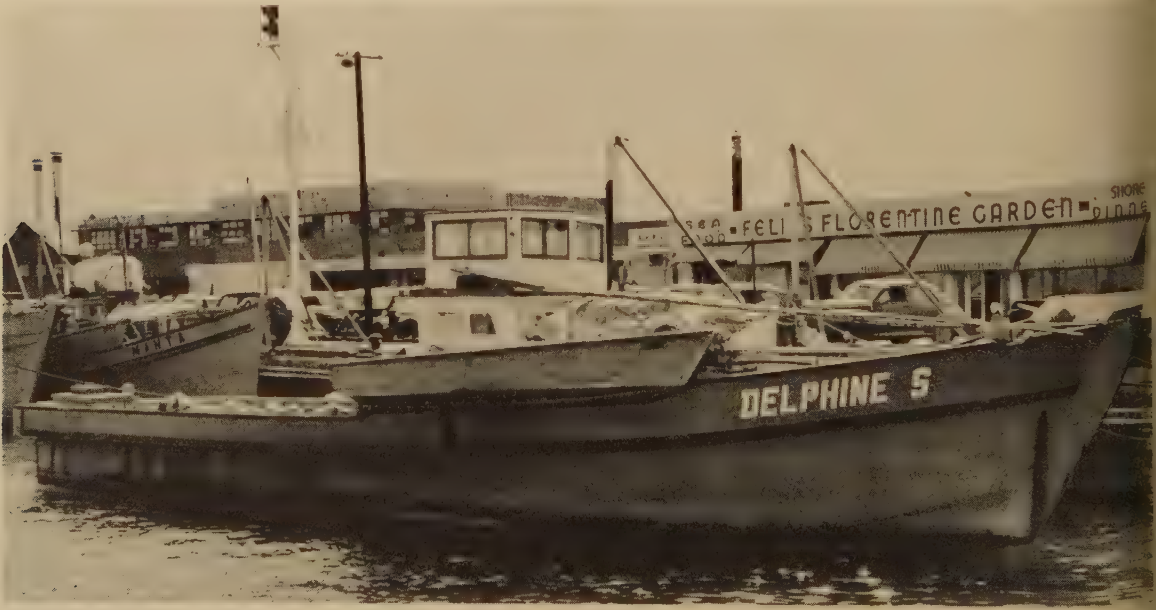

Fig. 1 - A long-line vessel (sampan) of the Honolulu fleet.

Since this is the only tuna long-line fishery in the central Pacific Ocean, a
rough understanding of it is important in evaluating data gathered from equato-
l regions which the Service's Pacific Oceanic Fishery Investigations (POFI) has
en exploring. June (1950) described the fishery in some detail; this report is in-
ded as a supplement and includes data on the catch and its trends and some ob-
rvations on the biology of the tunas.

This report, which covers the period from 1948 to 1952, is based largely on
tistics provided by the Division of Fish and Game, Board of Agriculture and
restry, Territory of Hawaii. These have been supplemented by information gath-
ed through discussions with fishermen and dealers and by examination of catches
ded at the local markets.

The principal center of the long-line fishery is Honolulu, where a fleet of 31 to
boats operates throughout the year and accounts for approximately 70 percent of
Territory's long-line landings. Next in importance is Hilo, on the island of
waii, with a fleet of about 10 boats. Smaller fleets are based at Kona on the is-
d of Hawaii and at Port Allen, Kauai.

The Hawaiian long-line boats are built along the lines of the Japanese sampan-
e live-bait boats, with a high and narrow bow, a modified V-bottom, and a mod-
ately low freeboard aft (fig. 1). The after deck has sufficient space for handling
fishing gear efficiently. They range in size from 40 to 63 feet in over-all length,
th about a 12-foot beam and a 6-foot draft on 60-foot boats. They are powered
th a Diesel main engine of 115 to 165 horsepower, usually of the high-speed type,
iving a single screw through a reduction gear.. Since none of the boats are e-
ipped with any sort of mechanical refrigeration, the fish are stored in crushed ice.
the outset of a trip the fish holds are packed with the necessary amount of cake
, generally in a ratio of about four pounds of ice to each expected pound of fish.
e larger boats carry a crew of 4 or 5 while the smaller boats employ a crew of
ly 2 or 3 men.

The gear is a drifting long-line made up in units referred to as "baskets" (June
50, Niska 1953). Each "basket" consists of a main line 140 to 200 fathoms long
spended at intervals by floats and supporting in turn a series of 5 or 6 vertical
anch lines. The hooks are usually baited with frozen sardines (*Sardinops caerulea*)
herring (*Clupea pallasii*). From 20 to 35 "baskets" of gear are connected in a
t, thus covering a considerable expanse of water.

SPECIES COMPOSITION OF THE LONG-LINE CATCH

The catches of the long-line boats include an interesting variety of tunas, spear-
shes, and miscellaneous pelagic fishes. Among the tunas, which constitute approx-
ately 65 percent of the landings; the yellowfin (*Neothunnus macropterus*) and the
g-eyed (*Parathunnus sibi*) are the two principal species. Albacore (*Germo alalunga*)
akes up from 1 to 4 percent of the total landings, whereas the long-line catch of
ipjack (*Katsuwonus pelamis*) is negligible and is practically never landed at the
arkets. Among the spearfishes, the black marlin (*Makaira mazara*) and the striped
arlin (*Makaira mitsukurii*) are the most abundant. Other species taken in lesser
antities are the sailfish (*Istiophorus orientalis*), short-nosed spearfish (*Tetrap-*
rus brevirostris), white marlin (*Makaira marlina*), and broadbill swordfish
iphias gladius). During the period studied, the several species of spearfishes to-
ther have constituted from 24 to 45 percent by weight of the annual long-line land-
s in the Territory. In addition to the tunas and spearfishes, small quantities of
hoo (*Acanthocybium solandri*), dolphin (*Coryphaena hippurus*), and sharks also ap-
ar in the landings.

Among the numerous types of fishing methods employed in Hawaiian waters,
long-line is responsible for practically all the landings of yellowfin, big-eyed,

and albacore tuna, and the various species of spearfishes. The skipjack pole-and-line fishery accounts for a few tons of small yellowfin which are taken at the surface when occurring in mixed schools with skipjack or in independent schools (table 14), but these amount to less than 4 percent of the annual landings of this species. Hand-line fishermen, operating in waters to about 50 fathoms in depth, contribute about 10 percent to the yellowfin landings (10- to 30-pound fish). A considerable number of spearfishes are also landed by the sport fishery, but here again, these constitute only a small percentage of the total spearfish landings.

Table 1 - Annual Landings by the Long-line Fishery in the Territory of Hawaii1/

Species	1952	1951	1950	1949	1948	1947	1946	19452/
	(Thousands of pounds)							
Yellowfin tuna ...	719	661	605	817	1,006	1,314	1,343	456
Big-eyed tuna ...	2,193	2,031	1,842	1,086	640	340	126	12
Albacore tuna ...	101	55	60	70	94	115	43	10
Black marlin	534	597	536	512	679	445	164	70
Striped marlin ...	371	382	570	431	453	384	202	41
Other spearfishes3/	47	138	171	206	283	270	155	42
Total4/	3,965	3,864	3,784	3,122	3,156	2,868	2,033	632
	(Percentage Composition)							
Tunas	76.0	71.1	66.3	63.2	55.2	61.7	74.4	75.9
Spearfishes	24.0	28.9	33.7	36.8	44.8	38.3	25.6	24.1

1/From records of the Territory of Hawaii Fish and Game Division. Landings shown for 1945-47 include catches made by other than long-line fishery.
2/1945 is considered a "war year" in which a restricted fishery operated and includes the July to December landings only.
3/Includes the sailfish, short-nosed spearfish, white marlin, and broadbill swordfish. Also included here are spearfishes which were not identified in the fishermen's reports. Detailed figures are not given for each species because they are frequently misidentified.
4/Totals may not be exact due to rounding off of figures.

Perhaps the most significant observation to be made from the records of the annual landings of the long-line fishery is the shift in dominance between the yellowfin and big-eyed tuna. The yellowfin, which reportedly was the dominant species of tuna in the prewar fishery,[1] declined in the catch from 1,343,000 pounds in 1946 to a low of 605,000 pounds in 1950 (table 1). Subsequently there was a small increase to 719,000 pounds in 1952. Meanwhile, the catch of big-eyed tuna increased tremendously and steadily from 126,000 pounds to 2,193,000 pounds. Thus the species composition of the tunas has changed from a predominance of yellowfin to that of big-eyed in 5 years (fig. 2).

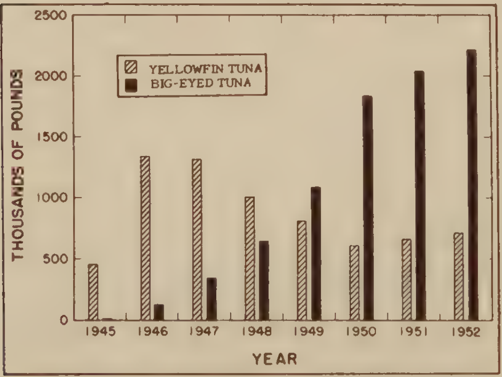

Fig. 2 - Annual landings of yellowfin and big-eyed tuna by the Hawaiian long-line fishery, 1945-52 (thousands of pounds).

SEASONAL VARIATIONS IN THE CATCH

A prominent feature of the Hawaiian long-line fishery is that its total production is relatively steady throughout the year. Although there are seasonal variations in abundance of the several principal species, the decline in abundance of one species is usually followed by an increase of another. Among the tunas, the big-eyed occur in greatest numbers during the winter months from October to May and the yellowfin from May to September (fig. 3 and table 16). Such seasonal variations in abundance are also seen among the spearfishes, although not as distinct as in the case of the tunas (fig. 3). The black marlin are generally abundant between July and October, while the striped marlin are plentiful during the winter months.

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[1] Detailed catch records are not available for prewar years.

Seasonal variation in species composition of the long-line catch is dependent on the movements and local abundance (or availability) of the fish rather than up- any changes in the practice of the fisher- en. These movements may be influenced by y of a number of environmental factors, of hich sea temperature is frequently believed be of importance. Bathythermograph ob- rvations between January 1941 and Novem- r 1947 in Hawaiian waters show that the onths of March and September have respec- vely the lowest and highest average temper- ures (Leipper and Anderson 1950). June and ecember are typical transition months. The aximum average surface temperature re- rded for this period was 82° F. and the inimum 66° F. Since the landings of yellow- n show a marked increase during the sum- er months, becoming greater as the water rms, and since the big-eyed tuna is cap- red in greatest numbers during the winter onths, the implications are that the yellowfin efers warm water and the big-eyed tuna oler water.

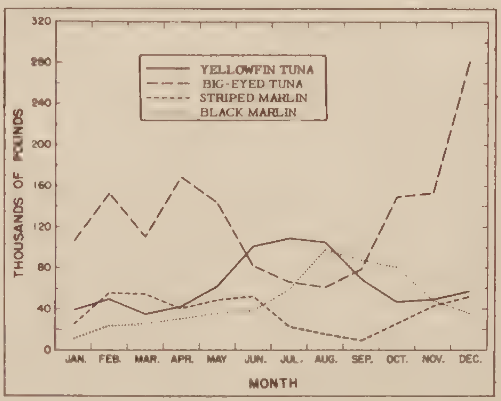

Fig. 3 - Average monthly landings (1948-52) of the four principal species by the Hawaiian long-line fishery (from catch statistics of the Territory of Hawaii Fish and Game Division).

However, not much reliance can be placed in a simple temperature relation- ip because yellowfin have been found in a much wider range of temperatures than curs in Hawaii. In Japanese waters yellowfin have been taken by long line when e surface temperature ranged from 14° C. (57.2° F.) to 27° C. (80.6° F.) (Taka- ma and Ando 1934). It is possible that the race of yellowfin occupying the central acific could, through adaptation, have different temperature limitations or prefer- ces than fish of the same species farther to the westward. Further research is cessary before it can be established whether or not sea temperature is at least rtly responsible for the marked seasonal changes in catch for these two species. e should not overlook the possibility, however, that temperature may merely be function of more complicated environmental factors, such as currents, chemical trients, or food organisms which influence the distribution of the fish.

June (1953) points to the possibility that the long-line fishery for yellowfin tuna based on a "spawning run," since the period of spawning of the Hawaiian yellowfin incides with its peak fishing season. A similar study being conducted on the big- ed tuna indicates that this species does not spawn in Hawaiian waters. Their ap- arance in greater numbers during the winter months is probably not directly re- ted to spawning.

Further mention should be made here of food as a possible factor influencing the asonal distribution of these species. The occurrence of yellowfin in greater num- rs during the summer is in all probability not a response to a particular type of od present in the area during that season. Reintjes and King (1953) have shown at this species feeds on a great variety of animal food from small plankton to fish e-third the length of the tuna, taking advantage of whatever food is most abundant the area at the time. Since it has been found, however, that plankton is slightly ore plentiful during summer than in winter in Hawaiian waters (King and Hida 54), the possibility remains that yellowfin are responding to a more abundant food pply.

CATCH PER UNIT OF EFFORT

Total landings may not indicate directly the magnitude of the population avail- le to the fishermen. Instead, landings tend to reflect the relation between the number of fish in the available population and the amount of effort expended. To measure changes in abundance of the fish population or to compare the relative abundance of fish in different areas, it is necessary to rely on some other measure, such as the catch per unit of effort, which in the case of the long-line fishery may conveniently be the catch per 100 hooks fished per day. Table 2 lists the catch rates (catch per 100 hooks per day) of tunas and spearfishes for the years 1949-52. These rates are based on information obtained by interviewing randomly-selected Honolulu fishermen at the termination of their trips.

Table 2 - Catch Rates (Numbers of Each Species per 100 Hooks Fished) of Tunas and Spearfishes in the Territory of Hawaii, 1949-1952[1] (Honolulu-based Long-line Fleet)

Species	Year	Month												Annual Average
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Yellowfin tuna ...	1952	0.07	0.26	0.11	0.14	0.47	1.36	1.19	0.92	0.33	0.08	0.05	0.16	0.43
Big-eyed tuna ...		3.71	2.58	2.08	4.98	2.60	0.38	0.29	0.25	0.45	0.95	1.47	1.82	1.80
Albacore tuna ...		0.01	0.01	0.00	0.00	0.12	0.67	0.42	0.26	0.28	0.22	0.06	0.15	0.18
Black marlin		0.05	0.08	0.05	0.06	0.09	0.07	0.12	0.40	0.34	0.40	0.16	0.07	0.16
Striped marlin ...		0.66	0.72	1.43	0.37	0.56	0.46	0.18	0.08	0.06	0.39	0.57	0.74	0.52
Other spearfish .		0.00	0.02	0.02	0.07	0.07	0.01	0.01	<0.01	0.00	0.00	0.02	<0.01	0.02
Total		4.50	3.66	3.69	5.62	3.92	2.96	2.20	1.90	1.45	2.05	2.33	2.95	3.10
Yellowfin tuna ...	1951	0.25	0.19	0.15	0.34	0.56	0.86	0.51	0.52	0.52	0.30	0.10	0.03	0.36
Big-eyed tuna ...		2.12	1.65	1.69	2.19	1.27	0.82	0.63	0.32	0.64	2.12	2.28	4.40	1.68
Albacore tuna ...		0.00	0.00	0.01	0.00	0.03	0.05	0.10	0.07	0.14	0.13	0.11	0.00	0.05
Black marlin		0.05	0.12	0.07	0.09	0.13	0.14	0.22	0.56	0.58	0.63	0.40	0.05	0.25
Striped marlin ...		0.76	0.98	0.91	0.84	0.82	0.77	0.26	0.05	0.03	0.14	0.19	0.36	0.51
Other spearfish[2]		0.00	0.09	0.04	0.13	0.12	0.03	0.02	0.03	0.05	0.11	0.10	0.00	0.06
Total[3]		3.18	3.03	2.87	3.54	2.93	2.67	1.75	1.56	1.97	3.43	3.18	4.84	2.92
Yellowfin tuna ...	1950	0.07	0.12	0.05	0.06	0.04	0.63	0.79	1.00	0.55	0.13	0.27	0.20	0.33
Big-eyed tuna ...		2.95	1.53	1.31	1.08	2.11	1.11	0.83	0.19	0.57	1.24	1.15	1.95	1.33
Albacore tuna ...		0.00	0.00	0.00	0.01	0.06	0.05	0.07	0.18	0.15	0.52	0.24	0.27	0.13
Black marlin		0.20	0.04	0.10	0.10	0.09	0.10	0.25	0.31	0.49	0.28	0.30	0.15	0.20
Striped marlin ...		1.47	1.15	2.06	1.16	0.54	1.25	0.65	0.09	0.06	0.50	1.29	1.15	0.95
Other spearfish ..		0.00	0.01	0.04	0.07	0.10	0.07	0.03	0.06	0.02	0.12	0.07	0.09	0.06
Total		4.69	2.86	3.56	2.49	2.94	3.21	2.63	1.83	1.85	2.78	3.32	3.81	3.00
Yellowfin tuna ...	1949	-	-	0.04	0.32	0.08	1.01	1.21	0.76	0.36	0.31	0.08	0.06	0.42
Big-eyed tuna ...		-	-	1.03	1.26	1.27	0.46	0.20	0.16	0.29	1.01	1.98	3.06	1.07
Albacore tuna ...		-	-	0.04	0.02	0.11	0.37	0.17	0.15	0.24	0.44	0.17	0.01	0.17
Black marlin		-	-	0.15	0.24	0.13	0.14	0.22	0.45	0.38	0.36	0.28	0.09	0.24
Striped marlin ...		-	-	2.07	1.33	0.65	0.81	0.37	0.03	0.10	0.42	0.59	0.50	0.69
Other spearfish[2]		-	-	0.06	0.13	0.05	0.09	0.02	0.03	0.02	0.07	0.13	0.20	0.08
Total[3]......		-	-	3.40	3.29	2.30	2.88	2.19	1.58	1.39	2.61	3.24	3.91	2.68

[1] Based on information obtained through interviewing randomly-selected Honolulu fishermen.
[2] Includes sailfish, short-nosed spearfish, white marlin, and broadbill swordfish.
[3] Columns may not agree exactly with the totals because figures were rounded off.

Table 3 - Average Catch Rates of the Japanese Tuna-Mothership Expeditions, June 1950 to October 1951[1]

Species	Number of Fish Per 100 Hooks
Yellowfin tuna ...	2.14
Big-eyed tuna ...	0.62
Albacore tuna ...	0.07
Skipjack tuna	0.05
Black marlin	0.53
Striped marlin ...	0.01
Other spearfish[2]	0.04
Total tunas and spearfishes[3] ..	3.45

[1] Reproduced in part from table 2 (Van Campen 1952).
[2] Largely sailfish and short-nosed spearfish.
[3] The total catch rate was 4.10, including sharks and other miscellaneous species.

The monthly catch rates in this table clearly indicate the seasonal variation in abundance of the principal species already mentioned in a foregoing section. Also notable is the fact that the total annual average catch rate has remained fairly constant during the years for which data are presented. The average long-line catch rate in Hawaiian waters of tunas and spearfishes combined is about 3 fish per 100 hooks, which compares favorably with the Japanese catch in their home waters, but falls below their catch in the various tropical and subtropical areas (June 1950). The Japanese tuna expeditions to the western equatorial Pacific waters between 1° and 13° N. latitude, 134° and 179° E. longitude, between June 1950 and October 1951, averaged 4.10 fish per 100 hooks, including sharks and other miscellaneous species (Van Campen 1952, also partly reproduced as table 3). Considering only the tunas and spearfishes, the average catch rate for the Japanese expedition was 3.45, somewhat higher than the Hawaiian catch rate.

FISHING EFFORT

The Honolulu long-line fleet consists of 31 to 33 boats which operate throughout e year. These boats remain at sea for a period of 10 to 12 days, fishing an average of 8 or 9 days per trip. Data on the number of trips made each month by these oats (table 4) have been obtained from records kept by the two auction markets and erefore include only trips on which some fish were caught and marketed.

Table 4 - Number of Boat Trips by Months, 1949-52[1]

Month	Year			
	1952	1951	1950	1949
anuary	40 (24)	26 (22)	32 (26)	15 (14)
ebruary	51 (28)	47 (26)	49 (28)	42 (29)
arch	56 (29)	57 (27)	50 (29)	37 (25)
pril	60 (27)	38 (26)	43 (27)	35 (26)
ay	51 (28)	54 (28)	54 (30)	44 (27)
une	61 (31)	49 (29)	50 (28)	45 (27)
uly	48 (30)	49 (27)	52 (27)	42 (28)
ugust	56 (29)	55 (30)	61 (30)	50 (28)
eptember	56 (30)	49 (29)	53 (29)	46 (28)
ctober	53 (31)	55 (30)	54 (31)	49 (29)
ovember	50 (30)	53 (28)	52 (30)	37 (27)
ecember	78 (31)	67 (30)	76 (30)	54 (28)
Total	660	599	626	496
verage number of trips per boat per year	21	18	20	16

The number of boats which participated during the month is enclosed in parentheses.

The number of trips made each month of the year is relatively steady with the xception of the holiday season. More trips are generally made in December to ke advantage of the great demand for fish, and fewer trips are made in January ecause a large part of the fleet remains in port on an extended celebration of the ew Year's holiday. The total trips made each year have increased from 496 in 49 to a high of 660 in 1952. Additional data obtained by interviewing fishermen ermit a closer scrutiny of the fishing effort (table 5). The average number of days shed per trip showed a steady decrease from 9.4 days in 1949 to 8.2 in 1952, teng to offset the increase in total trips made. As a result, the average number of ys fished per boat did not vary significantly from year to year.

Table 5 - Effort Expended by the Honolulu Long-Line Fleet, 1949-1952

Item	Year			
	1952	1951	1950	1949
otal boat trips	660	599	626	496
verage number of fishing days/trip	8.2	8.9	9.0	9.4
otal fishing days	5,412	5,331	5,634	4,662
umber of boats in fleet	32	33	31	32
verage number of fishing days per boat	169	162	182	146

The relatively high total of 660 trips in 1952 with a low average of 169 fishing ys per boat reflects the following abnormal circumstances. In April 1952 the catch te of big-eyed tuna reached the unusually high average of 4.98 per 100 hooks (table . As a consequence, the boats returned to port with capacity loads, flooding the cal market. The price of tuna fell from the March average of 36.8 cents per pound 22.2 cents in April (fig. 8). Faced with this situation, the boat owners voluntarily mited the larger boats to catches of 45 tuna and the smaller ones to 20. This action ten resulted in trips of shorter than normal duration, since the boats catching their mits were forced to return to port regardless of whether or not they had provisions capacity left for any more fishing.

In general, the data do not indicate any great changes in effort from year to year. The amount of effort being exerted by the fleet is by no means the maximum of which the fleet is capable, as it is generally agreed among the fishermen that the present limited market does not warrant the exertion of greater effort. In other words, the fishing effort is greatly regulated by market conditions so as to remain fairly constant from year to year as shown in table 5.

VARIATION IN CATCH BY AREAS

While some of the smaller boats of the Honolulu long-line fleet fish regularly in waters off Oahu, others travel 150-200 miles in quest of fish. In fact, boats from Honolulu often range from the waters off Hilo and Kona in the east to the waters off Kauai and Niihau in the west. Generally, however, all fishing is confined to waters within 20 miles from land (fig. 4). There are indications that the most productive areas of fishing tend to change with the season, and the majority of the boats shift their operations accordingly. However, for various reasons, such as the small size of the vessels, the small number of fishermen in the crews, and a desire to work in calm waters near home, some boats fish exclusively in the leeward waters of Oahu, regardless of the higher productivity of more distant areas.

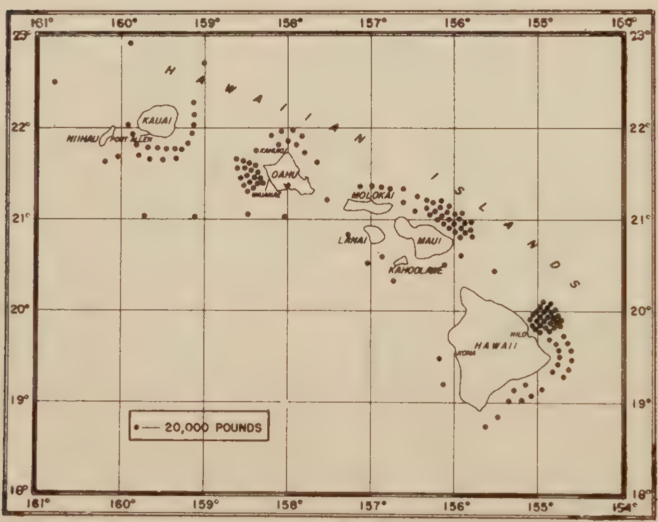

Fig. 4 - Total yellowfin and big-eyed tuna landings from Hawaiian waters during 1952. (From catch statistics of the Territory of Hawaii Fish and Game Division.)

Usually the area off Waianae, Oahu, provides the fishermen with fairly good catches for the greater part of the year. In 1952 over 50 percent of the total effort, in terms of number of trips made between June and September, was centered

Table 6 - Distribution of Effort by Honolulu Long-line Boats in 1952 in Percentage of Trips Made Each Month to the Various Areas[1]/

Month	Hawaii	Maui	Molokai-Lanai	Oahu		Kauai-Niihau
				Waianae	Kahuku	
	....	....	....	(Percent)	....	....
January	-	-	20.0	-	80.0	-
February ...	-	26.7	26.7	26.7	6.7	13.3
March	11.1	33.3	-	44.4	-	11.1
April	6.7	20.0	26.7	13.3	-	33.3
May	-	55.0	-	5.0	-	40.0
June	-	8.0	-	56.0	-	36.0
July	-	3.7	-	59.3	-	37.0
August	2.0	9.8	-	54.9	-	33.3
September ..	7.4	20.4	-	53.7	1.9	16.7
October	15.4	21.2	-	28.8	28.8	5.8
November ..	10.9	32.6	4.3	34.8	15.2	2.2
December ..	11.9	9.0	26.9	23.9	28.4	-
Annual Average ...	7.2	18.4	7.7	37.1	13.0	16.6

1/Calculated from information obtained by interviewing randomly-selected Honolulu fishermen at the termination of their trips. The number of trips on which these percentages are based are shown in table 7.

this area (table 6). Towards the latter part of the year, beginning around ctober, the major effort shifted to waters off windward Oahu, Hawaii, and to e Maui-Molokai-Lanai area, where better catches were experienced. Wind- ard waters are said to be more productive than leeward waters during the winter onths.

In studying variations in catch with areas, the 1952 data have been examined asmuch as these are the most complete. Detailed records of randomly-selected at trips are available only for the Honolulu fleet, as this information has been thered solely by interviewing fishermen in Honolulu. There are no comparative ta on the activities of long-line boats based on Hawaii and Kauai.

Table 7 - Average Monthly Tuna Catch Rates1/ (Number per 100 Hooks) in the Six Principal Areas in the Territory of Hawaii, 1952

Month	Hawaii	Maui	Molokai-Lanai	Oahu		Kauai-Niihau
				Waianae	Kahuku	
anuary	-	-	4.46(2)	-	3.34(8)	-
ebruary ...	-	5.40(4)	2.73(4)	1.80(4)	1.02(1)	1.56(2)
arch	1.84(1)	3.67(3)	-	1.57(4)	-	1.41(1)
pril	2.89(1)	6.09(3)	9.00(4)	2.63(2)	-	3.86(5)
ay	-	3.79(11)	-	4.42(1)	-	2.79(8)
ne	-	2.43(2)	-	2.10(14)	-	2.88(9)
ly	-	3.78(1)	-	1.90(16)	-	1.76(10)
ugust	0.99(1)	2.32(5)	-	1.02(28)	-	1.65(17)
eptember ..	0.76(4)	1.33(11)	-	1.03(29)	1.02(1)	2.14(9)
ctober	1.72(8)	1.35(11)	-	0.90(15)	1.21(15)	1.03(3)
ovember ..	3.00(5)	2.43(15)	1.56(2)	0.57(16)	1.24(7)	1.13(1)
ecember ..	2.97(8)	2.20(6)	2.79(18)	1.12(16)	1.90(19)	-
nnual verage ...	2.02	3.16	4.11	1.73	1.62	2.02

The tunas include yellowfin, big-eyed, and albacore. These catch rates are derived from data obtained by randomly interviewing Honolulu boat captains at the termination of their trips. The number of boat trips on which these monthly average rates are based is given in parentheses.

Table 7 shows the average monthly catch rates of tuna at the six principal fish- g areas. The seasonal shifting of the more productive areas is indicated. In gen- al, the Maui-Molokai-Lanai waters are seen to be most productive, while the wa- s off Oahu show the lowest catch rates.

BOAT EFFICIENCY

Fishermen the world over depend, in part, upon chance in making good catches. wever, it is more than pure luck alone. There are certain factors which are re- onsible for consistent differences in the catches made by the various boats of a et. These differences may lie in the intrinsic ability of the boat captains in lo- ting good fishing grounds, the skill and experience of the fishermen, or perhaps certain gear differences. The differences may also arise when certain boats con- stently fish in more productive waters than the others. The latter appears to be rticularly true of the situation existing in the Hawaiian long-line fishery.

Table 8 - Analysis of Variance of Monthly Catch Rates of 27 Boats for September to December 19521/

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	P
oats	26	58.4788	2.2492**	3.11	< 0.01
onths	3	24.6993	8.2331**	11.37	< 0.01
iscrepancy	78	56.4703	0.7240		
Total	107	139.6484			

Indicates a significant (P < 0.01) mean square value.

These months were selected because the most complete data are available for analysis. Four boats which did not fish regularly during this period were omitted from the analysis.

In a test to determine differences in boat efficiency, the average catch rates (as tunas per 100 hooks) of 27 Honolulu boats for the months of September through December 1952 were used. A two-way analysis of variance (Snedecor 1948) was used to test differences between boats, eliminating differences due to season (months). The data are presented in table 17. The test indicated highly significant differences between boats as well as between months (table 8).

Table 9 - Comparison of the Areas of Operation of Boats With High- and Low-Catch Rates During the Period September-December 1952[1]

Boats With High-Catch Rates[2] (13 in Number)			Boats With Low-Catch Rates[3] (14 in Number)		
Area	Number of Trips	Percent	Area	Number of Trips	Percent
Maui-Molokai	48	49	Oahu	78	77
Oahu	26	27	Maui-Molokai	11	11
Hawaii	18	19	Kauai	8	8
Kauai	5	5	Hawaii	4	4
Total.........	97	100	Total.........	101	100

[1] High- and low-catch boats were determined by the grand mean for this period of 1.62 tunas per 100 hooks fished.
[2] Above 1.62 tunas per 100 hooks.
[3] Below 1.62 tunas per 100 hooks.

A further examination of the data reveals that the significant between-boat differences are largely attributable to differences in the areas of operation. This is shown in table 9, which gives a comparison of the areas of operation between high- and low-catch boats. Each boat was classed either a high- or low-catch boat according to its mean catch rate for the 4-months period, high if the mean rate was greater than the grand mean of 1.62 tunas per 100 hooks (the grand mean of the 27 boats for the 4-months period) and low if less. Of 101 trips carried out by the 14 low-catch boats during the period, 77 percent were made in waters off Oahu, with the major concentration of effort in the leeward waters of Waianae. Furthermore, the data showed that five of these low-catch boats which had the lowest catch rates fished exclusively in Waianae waters. On the other hand, the 13 boats which experienced higher than average catch rates fished only 27 percent of the total of 97 trips in Oahu waters during the same period, having concentrated their efforts in the Maui-Molokai waters. Thus, some of the differences in catch rates between boats of the Hawaiian long-line fishery arise because certain boats consistently fish in one area, whether productive or not, while others operate in areas which are known to be most productive at any particular season.

SIZE OF THE TUNAS

Table 10 - Annual Average Weights of the Hawaiian Tunas

Species	Year			
	1952	1951	1950	1949
	.... (Pounds)			
Yellowfin tuna .	144.8	139.7	140.3	138.7
Big-eyed tuna .	162.1	158.5	157.3	160.1

The tunas taken in Hawaiian waters by long line are usually large fish. In general, the fishery has been catching fish over 90 pounds in weight with the bulk of the yellowfin falling between 100 and 160 pounds and the big-eyed between 100 and 200 pounds. Yellowfin in excess of 250 pounds and big-eyed weighing around 300 pounds are sometimes taken. The annual average weights of these two species are given in table 10. The weight-frequency distributions of these two species for 1952, by months,[2] are shown in figures 5 and 6, and these may be considered typical of those covering the period 1949-52.

A more detailed examination of the yellowfin weight data is presented in table 11. Here the yellowfin landings are broken down into components of various sizes, which are shown as percentages of the total landings. For this study the months of June, ly, and August have been selected for each year, 1948 to 1952, as these are the onths when the greatest yellowfin catches are recorded. The several components the landings indicate a regular distribution of size classes in the yellowfin catch om year to year, with a marked predominance of the 100- to 150-pound group, ich constitutes approximately 60 percent of the total. Less than 5 percent of the tch is made up of fish weighing less than 100 pounds.

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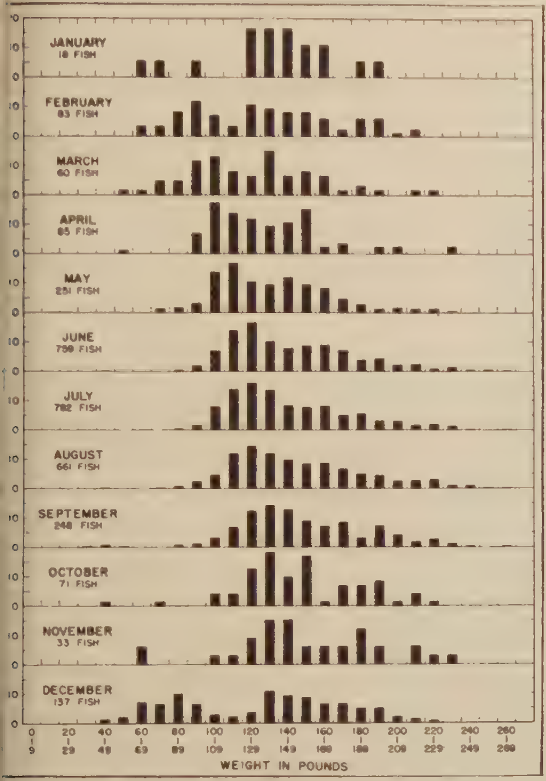
[2] Table 18 shows the monthly average weights of the tunas.



g. 5 - Monthly percentage weight-frequency distribution f yellowfin tuna landed in Honolulu in 1952.

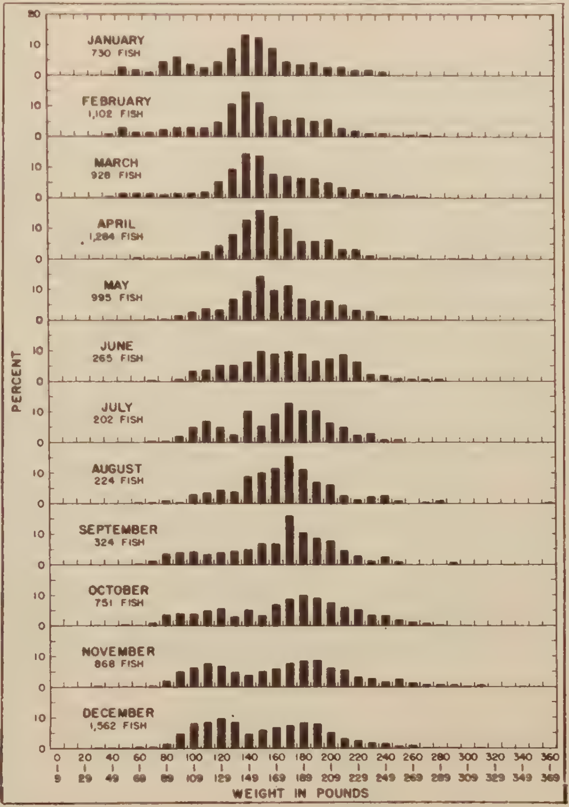


Fig. 6 - Monthly percentage weight-frequency distribution of big-eyed tuna landed in Honolulu in 1952.

Table 11 - Size Composition of the Yellowfin Catch, 1948-52[1]/

Year	Size Groups in Pounds					
	1-50	50-100	100-150	150-200	200-250	250-300
	(Percent)					
1952	0.1	2.7	56.2	32.3	8.3	0.4
1951	0.0	2.6	58.4	31.8	6.5	0.6
1950	0.2	3.9	67.2	23.5	5.0	0.1
1949	0.0	3.9	55.1	33.6	7.4	0.0
1948	0.0	3.9	56.0	33.2	6.8	0.1

[1]/Only the months of June, July, and August are represented here since these are the peak months of yellowfin landings.

SEX RATIO OF THE TUNAS

Examination of the landings at the Honolulu Market during 1949 and 1951 reveal- a predominance of males in both yellowfin and big-eyed tuna (table 12). Chi-square sts (Snedecor 1948) indicated significant deviations from the expected 50:50 sex tio.

This situation appears to be common also in other areas where long-line fishing is carried on. During the first Japanese postwar mothership tuna expedition in the western equatorial Pacific, the proportion of males in the yellowfin landings was usually found to be greater than that of females, the sex ratio sometimes running as high as 80 males to 20 females (Shimada 1951). Similar findings were made during several long-lining cruises of POFI vessels in the central Pacific equatorial waters (Murphy and Shomura 1953).

Table 12 - Sex Composition of Hawaiian Yellowfin and Big-eyed Tuna

Year	Tuna Species	Male	Female	Percentage of Males
		No.	No.	No.
1951	Yellowfin	547	313	63.6
	Big-eyed	733	542	57.5
1949	Yellowfin	114	65	63.7
	Big-eyed	346	238	59.2

The significance of these findings is not clear. We do not have sufficient evidence of seasonal changes in the sex ratios such as may be expected if these seasonal changes are directly related to the spawning cycle of the fish. As pointed out by Murphy and Shomura (1953), it may indicate such phenomena as differential growth or mortality. There are data which show that the sex ratios of both yellowfin and big-eyed tuna change with the size of fish, suggesting the possible occurrence of either differential growth or mortality in the populations. Shimada (1951) observed that female yellowfin tuna occurred more frequently among fish below 130 cm. in length (about 95 pounds) than among larger size groups, although at no time did he find the proportion of females exceeding that of males. Nakamura (1949) shows similar findings for the yellowfin taken in the East Philippine Sea between June and September 1937. He found 63 or 50.8 percent of 124 fish less than 37 kg. (81.4 pounds) to be males, or nearly a 50:50 sex ratio. For fish above this size he found 164 or 73.9 percent of 222 fish to be males. During the fifth Japanese mothership expedition in the western Pacific between March and June 1951, the author sampled a total of 1,293 big-eyed tuna, of which 70.5 percent were found to be males (table 13). Here again it was noticed that the predominance of males was especially pronounced among the larger fish. Out of 949 fish measuring over 120 cm. in total length (about 80 pounds), 77.3 percent were males. In the other group of smaller fish, males constituted only 51.7 percent of a total of 344 individuals examined. Thus the sex ratio in the catch below 80 or 90 pounds is about equal, whereas the males predominate among the larger big-eyed and yellowfin tuna.

Table 13 - Sex Determination on 1,293 Big-eyed Tuna Captured During the Fifth Japanese Mothership-Type Tuna Expedition in the Western Equatorial Pacific Ocean April-June 1951

Month	<120 cm. (80 pounds)			>120 cm. (80 pounds)		
	Males	Females	Percentage of Males	Males	Females	Percentage of Males
	No.	No.	%	No.	No.	%
April	31	29	51.7	111	43	72.1
May	93	89	51.1	454	143	76.0
June	54	48	52.9	169	29	85.4
Total .	178	166	51.7	734	215	77.3

PREDICTING THE LONG-LINE CATCH OF YELLOWFIN

Yellowfin smaller than 50 pounds are seldom taken by the Hawaiian long-line fishery and those below 20 pounds are practically never caught (fig. 5). Smaller fish, on the other hand, are frequently taken by the skipjack pole-and-line fishery, which finds them at the surface either mixed with schools of skipjack or in independent schools. The absence of small fish in the long-line catch may result either from a selective action of the gear or from a general absence of small fish in the subsurface pulation. The second alternative appears to be more plausible as Murphy and omura (1953) have pointed out that there is no reason to believe that the long line selective as to sizes of fish ıen since skipjack as small as pounds have often been captured this method. In addition, small llowfin have been taken by long e in the vicinity of the Line Is- nds in the central Pacific, indi- ting that small fish will be ught if present in the population.

Fig. 7 - POFI scientists examining tunas and spearfishes on the auction floor of the Honolulu Market.

The surface-caught yellowfin e generally small- to medium- ed fish and appear to be a seg- nt of the yellowfin population ich is ecologically separated in- surface and subsurface groups. e surface fish may descend to eper levels after attaining a rtain age or size. If this as- mption is true, it may be rea- nable to expect the abundance of rface fish in one year to indi- te the abundance of subsurface h a few years later. Such a re- ionship, if real, would be of me value to the fishery in pre- cting the abundance of yellowfin ew years in advance. Since the long-line catches of yellowfin are largely made of a few year-classes, with fish believed to be in their third year (Moore 1951) ntributing the largest percentage to the fishery, the size of this year-class, at ast, may be a reflection of the abundance of surface fish two years previous.

Table 14 - Monthly Landings of Surface Yellowfin by the Hawaiian Skipjack Fishery, 1948-52[1]

Month	1953	1952	1951	1950	1949	1948
	(Pounds)					
anuary	-	-	1,598	7,131	763	6,911
ebruary	-	2,372	632	1,618	1,301	387
arch	-	554	40	1,061	3,073	6,810
pril	-	4,892	4,087	7,672	1,303	5,620
ay	-	1,663	1,552	3,151	1,532	1,183
ıne	-	238	118	6,549	139	1,892
ıly	-	11,946	117	1,017	3,342	838
ugust	-	985	7,379	6,798	13,141	638
eptember	-	1,090	8,502	7,224	-	1,323
ctober	-	5,148	98	132	12,071	396
ovember	-	2,413	83	3,416	-	531
ecember	-	146	891	26	185	-
Annual total	-	31,447	25,097	45,795	36,850	26,529
ellowfin landings by long-ine fishery	[2]535,000	719,000	661,000	605,000	-	-

[1] From records provided by the Territory of Hawaii Fish and Game Division.
[2] Approximate long-line landings of yellowfin for 1953. Data not available by months.

The landings of surface yellowfin by the skipjack fishery for the years 1948 to 52 are presented in table 14. Also listed in the same table are the yellowfin landings by the long-line fishery for 1950 through 1953. There appears to be some relationship between the total landings of surface fish in one year with the catch of subsurface fish two years later; e.g., the 1948 landings of 26,529 pounds of surface fish with the 1950 catch of 605,000 pounds of subsurface fish; the 1949 landings of 36,850 pounds with the 1951 catch of 661,000 pounds; and the 1950 landings of 45,795 pounds with the 1952 catch of 719,000 pounds. The catch statistics for the year 1953 indicate estimated yellowfin landings by the long-line fishery of 535,000 pounds, a drop from previous years, which again agrees with the reduced surface yellowfin landings of 25,097 pounds in 1951. Unfortunately, available data are far too scanty to draw any conclusions. Even if such a relationship actually exists, we cannot expect to find perfect correlations as there are numerous factors which tend to make surface sampling inadequate and probably inaccurate. In the first place, the total landings may not indicate the true abundance of surface yellowfin in these waters as the skipjack fishermen may often forego schools of yellowfin when skipjack schools are numerous. Again, the amount of effort expended by the skipjack fleet from year to year might vary so much that total landings would not be indicative even of relative abundance of the species.

FISH PRICES AND VALUE OF LANDINGS

The catch of a Honolulu long-line boat is unloaded at one of two auction markets where buyers from the several fresh fish markets, as well as individual fish peddlers, bid for the fish (fig. 7). Since at the present time there are no outlets for canning of these large tunas, the only markets are those for fresh fish. Fresh tuna is in great demand, especially by the island's oriental population, for consumption as sashimi (raw fish). Fortunately for the fishing industry, big fish are preferred for sashimi because of the higher oil content, which supposedly improves the flavor. The bulk of the spearfishes is sold to processors for use in making fish cakes (kamaboko), while a small part is handled as fresh fish.

While the local skipjack fishermen enjoy a relatively steady contract price because their catches are canned, the prices realized by the long-line fishermen fluctuate very widely. Only in times of extremely good catches are the canneries not able to absorb all of the fish which are landed by the skipjack fishery. These fish may be canned and held in warehouses, but the large tunas and spearfishes which are presently handled only as fresh fish are highly perishable, and consequently the prices paid for them are largely controlled by the factors of supply and demand. It is therefore not unusual that prices paid for long line-caught fish vary from day to day or even between the two auction markets on the same day.

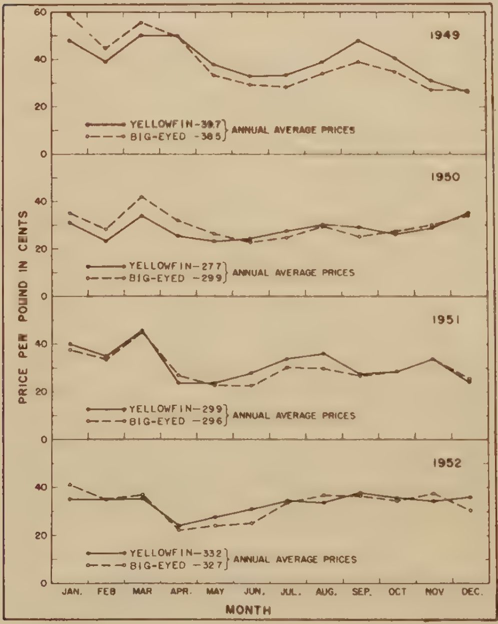


Fig. 8 - Average monthly prices paid to the fishermen for yellowfin and big-eyed tuna, 1949-52 (from records of the Territory of Hawaii Fish and Game Division).

Figure 8 presents graphically the monthly average prices of yellowfin and big-eyed tuna at the auction markets between 1949 and 1952. These prices are essentially what the fishermen receive for their catches, although some deductions are made by the auction firms for services rendered. Annual average prices for both species do not differ significantly although yellowfin generally commands a slightly higher price than big-eyed tuna. The prices are determined more by the size of the fish and condition of the meat (such as color and texture) than by species.

The ever-fluctuating fish price is an important factor which tends to influence intensity of fishing. As shown in table 15, the annual values do not show any nificant trend but remain rather steady at slightly over a million dollars. This not in keeping with the steadily increasing annual landings (table 1), but appears e the result of a limited market capacity which controls the price of fish accord- to supply and demand. As seen in figure 8, the annual average price for both cies of tuna dropped markedly from about 40 cents per pound in 1949 to less than cents in 1950, and has not shown any appreciable recovery since.

Table 15 - Value of Fish to the Fishermen Landed by the Long-line Fishery in the Territory of Hawaii, 1948-1952[1]

Species	1952	1951	1950	1949	1948
	$	$	$	$	$
llowfin tuna	230,412	206,038	178,111	313,024	438,611
g-eyed tuna	684,726	600,361	548,526	376,135	294,422
acore tuna	22,611	13,933	11,591	23,894	32,541
arfishes	309,030	335,092	322,114	412,157	504,422
Total	1,246,780	1,155,424	1,060,342	1,125,210	1,269,995

mpiled from records of Territory of Hawaii Fish and Game Division.

Although all or nearly all of the fish are presently being absorbed by the buyers, prices paid for them are often very low. While it is generally agreed that the stal and offshore waters of the Hawaiian Islands contain a dependable supply of s and spearfishes to sustain a much more intensive long-line fishery, the limited ket constitutes a serious block to any such expansion.

Table 16 - Monthly Landings (In Thousands of Pounds) by the Hawaiian Long-line Fishery, 1948-52[1]

Species	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
llowfin tuna ...	1952	28	41	34	49	78	113	120	128	64	28	14	22
-eyed tuna ...		167	196	133	357	224	96	71	69	116	216	182	366
acore tuna ...		1	1	1	10	4	19	15	14	16	11	2	8
arfishes		30	86	66	52	64	69	64	119	121	124	79	79
Total		225	324	233	468	370	297	270	330	317	379	277	475
lowfin tuna ...	1951	10	18	30	41	76	98	80	60	83	53	45	67
-eyed tuna ...		142	172	131	197	204	110	115	105	109	200	177	370
acore tuna ...		1	1	1	1	1	3	5	3	4	6	6	26
arfishes		37	46	90	79	135	104	88	136	114	121	108	59
Total		190	236	252	317	416	315	288	304	310	380	336	522
lowfin tuna ...	1950	14	22	13	23	39	73	100	121	66	54	45	35
-eyed tuna ...		135	212	138	154	191	148	114	90	103	150	136	272
acore tuna ...		-	1	2	1	2	4	9	10	6	8	6	13
arfishes		44	111	118	90	113	111	87	116	123	137	120	108
Total		193	346	271	267	344	335	310	338	299	349	307	428
lowfin tuna ...	1949	67	79	34	49	69	120	128	91	49	31	40	60
-eyed tuna ...		33	74	78	62	69	42	16	23	49	136	200	304
acore tuna ...		6	11	4	7	3	6	5	5	7	8	6	2
arfishes		55	141	108	108	110	93	80	113	66	104	89	83
Total		161	305	224	226	251	261	230	232	172	278	335	448
lowfin tuna ...	1948	77	89	64	50	42	99	114	121	85	67	99	99
-eyed tuna ...		55	108	73	76	35	19	19	16	22	41	77	99
acore tuna ...		1	6	2	15	13	11	5	12	13	9	4	2
arfishes[2] ...		46	99	96	84	76	142	157	159	122	111	133	191
Total[3]		179	302	236	225	166	271	295	308	242	228	313	391

piled from catch statistics of the Territory of Hawaii Fish and Game Division.

udes black marlin, striped marlin, and lesser quantities of sailfish, white marlin, broadbill swordfish, and short-nosed spearfish.

als may not be exact due to rounding off figures.

Table 17 - Analysis of the Catch Rates (as Tunas per 100 Hooks) of 27 Boats (September to December) by Months

Boat	Month				Mean	Boat	Month				Mean
	Sept.	Oct.	Nov.	Dec.			Sept.	Oct.	Nov.	Dec.	
1	0.67	0.52	0.99	0.47	0.66	15	0.91	1.38	2.27	1.97	1.63
2	0.97	0.55	0.20	1.22	0.74	16	1.83	1.90	0.86	1.98	1.64
3	0.64	1.05	0.31	1.24	0.81	17	1.38	1.48	2.32	1.64	1.70
4	0.80	1.12	0.36	1.02	0.82	18	0.76	1.29	1.77	3.13	1.74
5	1.08	0.98	0.37	1.18	0.90	19	1.52	1.19	2.03	2.48	1.80
6	1.02	0.54	0.66	1.86	1.02	20	0.78	1.08	2.90	3.33	2.02
7	1.09	1.26	0.31	1.53	1.05	21	0.67	0.72	4.74	2.09	2.06
8	0.67	0.90	1.15	1.57	1.07	22	1.34	1.60	3.48	1.96	2.10
9	1.61	1.02	0.68	1.17	1.12	23	1.71	2.01	2.56	2.61	2.22
10	1.22	1.56	0.87	0.92	1.14	24	1.46	1.67	2.16	4.03	2.33
11	0.57	0.84	1.20	2.11	1.18	25	1.72	1.20	5.06	3.65	2.91
12	0.92	0.89	1.92	1.78	1.38	26	1.32	1.78	3.63	5.71	3.11
13	0.80	1.50	1.32	2.37	1.50	27	1.92	1.79	5.69	5.08	3.62
14	1.64	0.41	0.22	3.89	1.54	Grand mean of 27 boats					1.62

Table 18 - Monthly Average Weights of Yellowfin and Big-eyed Tuna in the Landings of the Hawaiian Long-line Fishery

Month	Yellowfin tuna				Big-eyed tuna			
	1952	1951	1950	1949	1952	1951	1950	1949
	.... (Pounds)							
January	136.7	152.3	98.8	104.2	147.5	152.2	156.3	175.0
February	131.5	125.5	107.0	117.8	153.4	150.2	151.7	150.0
March	126.0	105.4	120.2	113.5	159.5	144.5	153.4	141.0
April	133.1	116.2	117.5	122.7	165.6	152.1	154.6	156.1
May	136.3	126.3	117.0	131.8	168.2	160.3	157.1	153.7
June	146.7	140.4	136.4	144.0	176.4	164.1	165.0	171.3
July	145.3	141.5	136.6	143.5	167.3	168.3	163.7	184.0
August	149.5	151.6	144.5	138.1	170.7	157.6	158.5	183.4
September	152.6	151.1	158.4	145.7	169.8	151.8	149.3	170.5
October	150.8	142.1	146.8	140.2	172.3	152.8	155.1	168.7
November	155.1	139.1	143.3	150.0	167.8	170.5	155.0	167.0
December	129.2	154.5	136.2	119.7	155.7	165.5	159.6	159.3
Annual average ..	144.8	139.7	140.3	138.7	162.1	158.5	157.3	160.1

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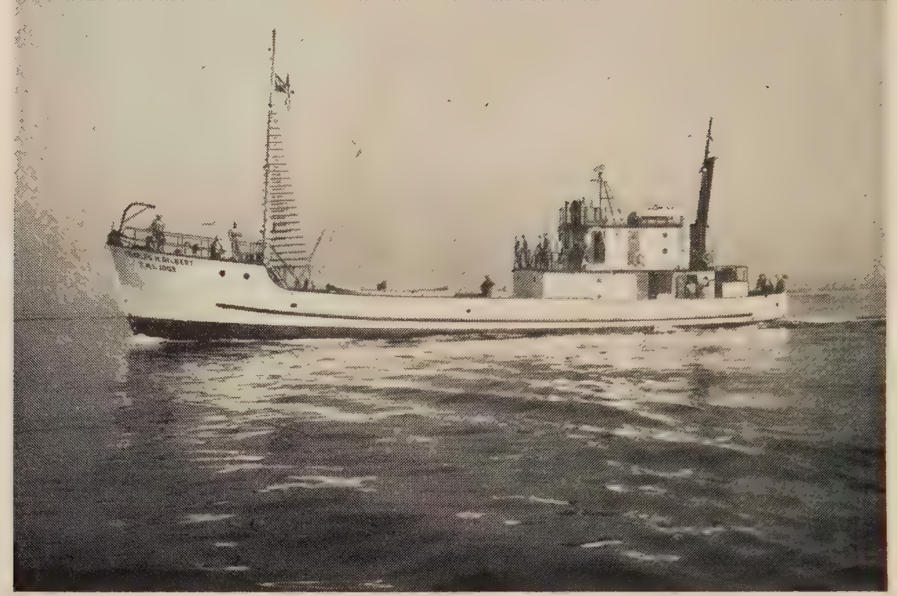
ACKNOWLEDGMENT

The Fish and Game Division of the Territory of Hawaii, Board of Agriculture and Forestry, has provided much of the data on which this paper is based. The generous cooperation of the various dealers and officials of the Honolulu Market Place, the Kyodo Fishing Company, the United Fishing Agency, and the Hawaii Fishing Company in allowing examination and sampling of their fish is gratefully acknowledged. The captains and crews of the Honolulu long-line boats have been very cooperative in supplying information pertaining to fishing operations. The interview method of obtaining information was initiated in 1949 by Fred C. June, Fishery Research Biologist, formerly with the staff of the Service's Pacific Oceanic Fishery Investigations. Many others have helped in the collection of data, including fishery research biologists Isaac I. Ikehara, Richard Shomura, and Heeny Yuen. The figures were prepared by Tamotsu Nakata, draftsman for POFI.



The Charles H. Gilbert of the Pacific Oceanic Fishery Investigations. Photograph taken in San Pedro after alteration, which included the addition of a 28-foot amidships section.

TUNA BAIT SURVEY

In the Marquesas and Tuamotus

By WILLIAM F. ROYCE
Fishery Research Biologist
Pacific Oceanic Fishery Investigations

THERE was good tuna bait in the Marquesas, but in the Tuamotus it was scarce and difficult to catch. This was the conclusion reached after a reconnaissance by scientists and fishermen from the Pacific Oceanic Fishery Investigations during a 10-day visit to the islands with the vessel *Charles H. Gilbert.* The baiting in the Marquesas was similar to that found by the *Hawaiian Tuna* and the *Challenger* which fished the area in earlier years.

Sailing from San Pedro on February 18, 1954, the *Gilbert* fished tuna longline gear south from California across the Equator and then went west in order to refuel at Tahiti. The first stop was in the Marquesas, which are about 3,000 miles southwest of California at approximately 10° S. latitude. They are high volcanic islands, extremely rugged, with vertical cliffs rising from the ocean around most of their shores. Administered by the French government from headquarters in Tahiti, they are inhabited by only about 3,000 people, whose principal occupation is growing copra.

Baiting in the Marquesas

The *Gilbert* dropped anchor in the

After catching these and bailing them alive out of the net because we had no reason to keep them (we were not equipped for live bait tuna fishing), we scouted the rest of the beach and estimated that we could have caught 1,550 scoops more in schools of worthwhile size.

About 80% of this bait was a miniature herring called "sardine" by the local people.. We measured several hundred which averaged $3\frac{1}{2}$ inches long. In some schools these were mixed with goatfish of the same size.

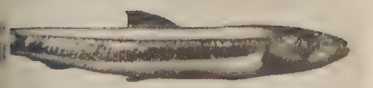
The next day we scouted Taipi Bay, about 10 miles to the east on the same island. This is a little larger bay at the mouth of a stream and here we found another excellent school of the sardines. It was in about 12 feet of water, which was too deep for our seine, but it was estimated to contain at least 800 scoops. Other smaller schools were

protected from the swells. Here w found the same sardine, but did no catch any because these schools wer in 12 to 15 feet of water and the sur running on the beach was too heav to permit the use of our beach sein

This Marquesan sardine, said b the natives to be present all of th time, unquestionably is the sardin which other vessels have found i good quantities on most of the island at this season of the year. Howeve they may not always be abundan because we have one report of a ves sel which was unable to locate bai in the Marquesas during the middl of July.

In addition to the sardines, ther were signs of other species suitabl for bait. The goatfish have been men tioned and a few hundred scoop could have been taken. In addition we saw some small jack mackerel o scad schooled around the wharf i Taiohae Bay and numerous signs o unidentified schooling fish in th deeper waters of the bay.

Three different kinds of nets should take almost any of these fish. Ou bait seine, which is 9 feet deep and 40 fathoms long, was almost idea



erere of the Tuamotus, fairly abundant
ll and hard to catch. This little round
is similar to the Hawaiian piha, which
used during the first day after cap-

which could be pursed around
rger, faster swimming schools
deeper waters of the bays.

sardines seemed to be a hardy
ish and our Hawaiian fisher-
udged it would be satisfactory
ait. It was vigorous in the seine
id not tend to suffocate easily,
id it lose a great many scales.
d not try to keep it in the tank
eck its hardiness. Another ves-
hich caught more than 1.000
s at the island of Hiva Oa.
that most of the bait died in
two days. However, we have
formation on whether it was
ed carefully or not.

hough we found this bait abun-
n the bays we visited, there are
ew bays to provide bait for
clippers. The islands are small
a land area less than 10% of
f the Hawaiian Islands, which
rt only about 25 sampans. The
show less than 20 miles of
and shoal areas where seining
rs practical. (This is only about
f the shore line of the Gulf of
a.) The rest of the shore is
with rocks and precipitous

g in the Tuamotus

en we reached the Tuamotus,
und the baiting conditions much
ent. These are all low coral
situated about 400 miles south-
f the Marquesas. Many of them
navigable lagoons which reach
40 miles in size, and thus there
enormous area where bait fish
occur.

visited the atolls of Raroia,
mo, Raraka, and Fakarava. In
these except Raraka the passes
navigable by the *Gilbert* and
we entered the lagoons and anchored. In Raraka it was reported by the natives that the copra schooner came in, but the chart was not detailed enough for us to try it. In all of these atolls the lagoons ranged from 100 to 200 feet in depth, but were sprinkled with coral heads, reaching almost to the surface. They were navigable in good light, however, when the coral heads could be seen to a depth of 30 feet or more in the clear transparent water. We took the *Gilbert* around some of the lagoons but mostly we scouted from a skiff and from shore.

Plenty of bait fish species were found, including goatfish, mullet, aholehole, jack mackerel, and a small round herring. However, none of these occurred in large schools in good seining areas. Some bait could be had, but from our experience a crew would be lucky to catch more than 20 or 30 buckets in a day's baiting. Strangely, the sardine so common in the Marquesas does not occur in the Tuamotus. None of the native fishermen recognized it.

The mullets and goatfish were scattered all around the edges of the lagoons in amongst coral heads on sandy or coral bottom. Here they usually escaped our seine or our net fouled so thoroughly on the coral that we could not move it.

The best bait was probably the small round herring which is called piherere by the natives, but it wouldn't be easy to catch it. We saw it commonly in schools of from 10 to perhaps 50 scoops around the coral heads in the lagoons and saw several schools of skipjack or yellowfin feeding on them. These piherere would be extremely difficult to catch around the coral heads, the sides of which are usually vertical for 20 to 40 feet and then slope precipitously into the deeper water. We never found this species in a good seining location, but in running over one lagoon with the *Gilbert* we picked up two echoes on our sounding machine which probably were from this species at a level of 30 to 40 feet in approximately 100 feet of water. Here they might be taken with a purse seine.

Besides being difficult to catch, this species may not be satisfactory bait because it is so small and delicate. All of the piherere seen would go through the ¼-inch square mesh of our bait seine. The schools were usually of mixed sizes, 1¼ to 2 inches in length, and the larger ones were frequently fully mature males and females, so we presume that they do not attain a much larger size. It is similar to the Hawaiian piha, which must be used during the day after capture.

We tried night lighting in all of the lagoons except Raraka with a small trap especially designed for the collection of scientific specimens. This trap took a few piherere, but at no time did we see enough fish schooled around the light to indicate that a larger net might be worthwhile. Night baiting would probably not be very productive.

Of course, there are many islands in the Tuamotu group which we did not visit, but we found that the fish populations in the four that we did visit were very similar and probably baiting in the other lagoons is not much better. This guess is supported by a report from another vessel, which stopped at Rangiroa, one of the larger atolls, and found no bait in two days' scouting. Thus, we conclude that bait is much harder to catch in the Tuamotus than in the Marquesas.

Tuna in the Marquesas

Not only is bait available in the Marquesas but so are tuna. While approaching and leaving the islands we found plenty of birds working over fish schools, some of which were seen to be 10- to 30-pound yellowfin. Working flocks were especially common just south of Ua Huka and running south from Ua Pu we saw 19 large flocks in 1½ hours—which is more per hour than we have seen off Hawaii in months of scouting.

Yellowfin and skipjack have been fished off the Marquesas at this season in other years. Good catches have been made, but also many wild schools have been reported along with poor fishing despite many bird signs and schools of fish.

So no guarantees about the fishing in the Marquesas can be made. Bait in good quantities for a few boats has been available in three different

PROGRESS IN PACIFIC OCEANIC FISHERY INVESTIGATIONS 1950–53

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 116

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

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Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

PROGRESS
IN
PACIFIC OCEANIC FISHERY INVESTIGATIONS
1950 - 53

HUGH M SMITH
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M/V HUGH M. SMITH

By

Oscar E. Sette and the
Staff of P.O.F.I.

Special Scientific Report: Fisheries No. 116

WASHINGTON: FEBRUARY 1954

The Pacific Oceanic Fishery Investigations of the Fish and Wildlife Service is based at Honolulu, Hawaii, for the purpose of carrying out Public Law 329--80th Congress, which was enacted August 4, 1947. This law declares:

"That it is the policy of the United States to provide for the exploration, investigation, development, and maintenance of the fishing resources and development of the high seas fishing industry of the Territories and island possessions of the United States in the tropical and subtropical Pacific Ocean and intervening seas, for the benefit of the residents of the Territory of Hawaii and Pacific island possessions and of the people of the United States."

Following the appropriation of funds in 1948 and the subsequent acquisition and conversion of three seagoing vessels, construction of a laboratory, and a preliminary reconnaissance of the problem, sea work began early in 1950.

The reconnaissance had determined that the several kinds of tuna, notably yellowfin and skipjack, formed the most promising mid-Pacific high-seas fishery resource. A semi-private and several private attempts to develop mid-Pacific tuna fisheries had failed during the several years prior to 1950. These had been undertaken with the idea of obtaining quick results by simply sending skilled fishermen on California-type tuna fishing vessels to fish for tuna at a number of places presumed to be favorable. Some tuna were caught during each of the ventures but not in paying quantities.

With this proof of the difficulties involved, we approached our task on a longer-term basis and from the viewpoint that fish stocks large enough to support a high-seas fishing industry could exist only where ocean conditions specially favored the production of plentiful foodstuff for the fish. This involved study of the oceanography, of the fish, and of the animals they feed upon, combined with fishing surveys designed to estimate the abundance of fish and to determine the methods by which they can be caught in commercially adequate quantities.

After 3 years of sea work results are emerging which appear to have immediate practical fishery significance and to constitute substantial scientific contribution. Some reports on separate phases have been published and others are being prepared. Pending their completion, our findings are summarized here briefly and pictorially in what we hope is a clear, simple, and useful form. To avoid the distraction of interspersing references to sources, a summary of the kind and quantity of data underlying the several charts, graphs, and statements is appended, together with a list of the publications resulting from our work.

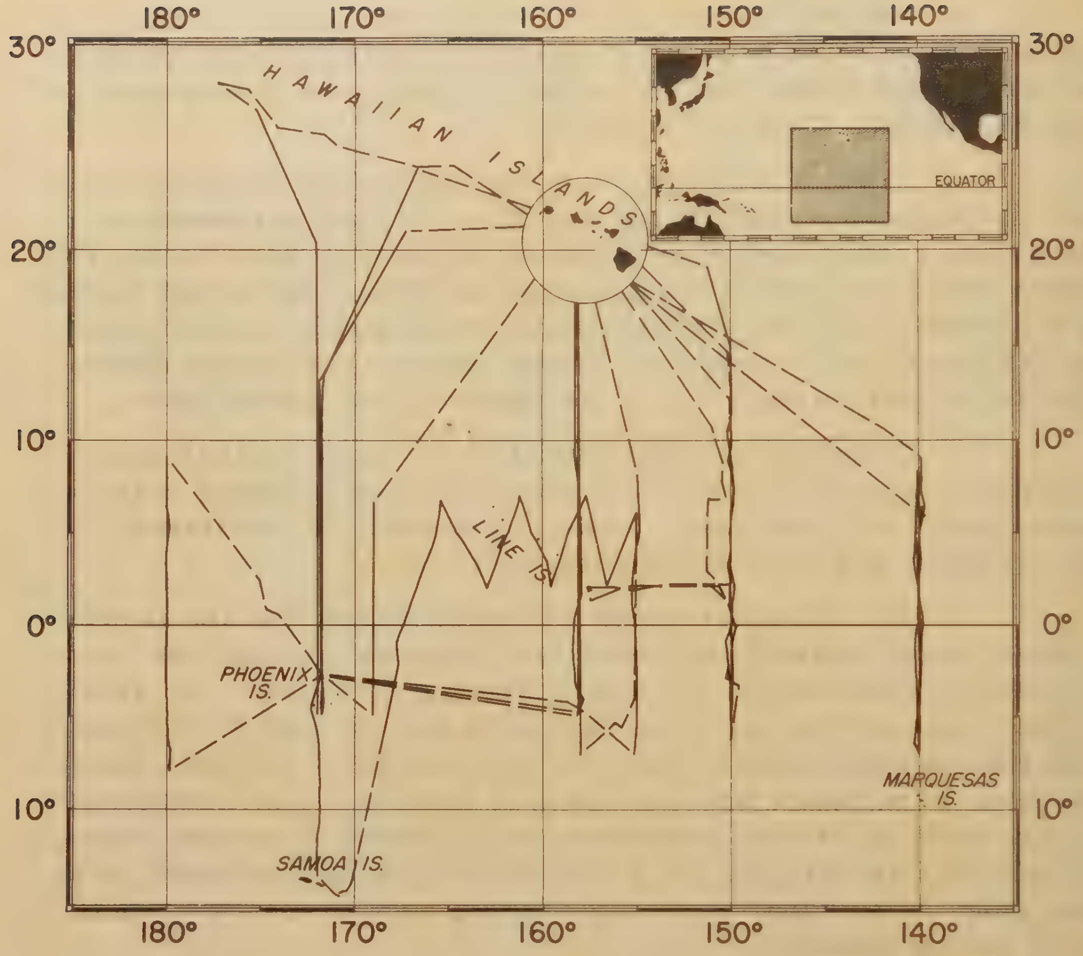
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Figure l. Equatorial Hydrographic Cruises. Our method of investigating high seas fishery resources is to first understand the seas in which the fish have to make their living. Since January 1950 we have crossed and recrossed the ocean area lying south of the Hawaiian archipelago along the tracks shown in this chart, taking temperatures, salinities, phosphates, and plankton samples at 60-mile intervals along the solid lines.

From these observations and measurements we have been able to determine the general circulation features as shown on the next figure. Also, we learned where the surface waters are enriched, undoubtedly providing more abundant food for the tuna. These surveys have shown that the oceanic conditions change with time and the indications are that these changes may be on the order of but a few days.

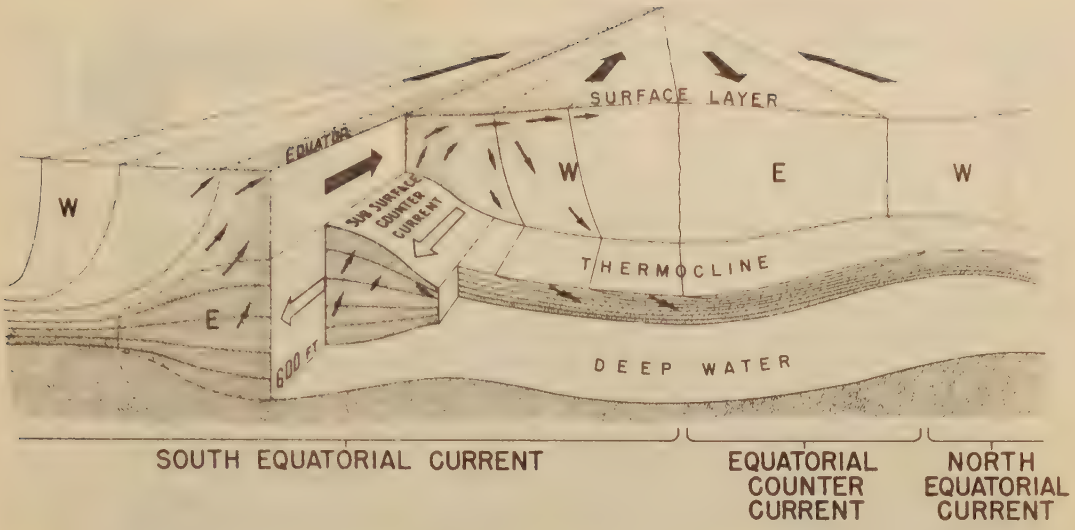
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Figure 2. 1953 Concept of Equatorial Circulation. As a result of our studies we now have an idea why the equatorial waters are more productive than those to the north and south. This idea has been illustrated in the "slice" of the ocean shown above. Visualize that we have sliced the ocean along longitude 150° and are looking towards the west with north to our right and south to our left. The surface currents are shown by broad arrows and the vertical temperature structure by the fine lines of equal temperature. However, we wish to focus your attention on the waters at the Equator. Under the influence of the steady southeast tradewinds the deep water comes to the surface and moves northward as shown by the smaller solid black arrows. This sets up a chain of events that ends with good tuna fishing. The upward moving water brings phosphates, nitrates, and other nutrients to the lighted zone and phytoplankton (one-celled plants) multiplies rapidly. The zooplankton (tiny animals) feeds on the plants and in turn multiplies, drifting slowly north with the water. Larger crustacea, squids, and small fish gather to feed on the zooplankton. The tunas, the final step in the oceanic production line, concentrate here where there is good feeding much more of the time than elsewhere.

The eastward flowing subsurface countercurrent was recently discovered in our work. Its significance to the circulation and to the productivity of the system is not yet known.

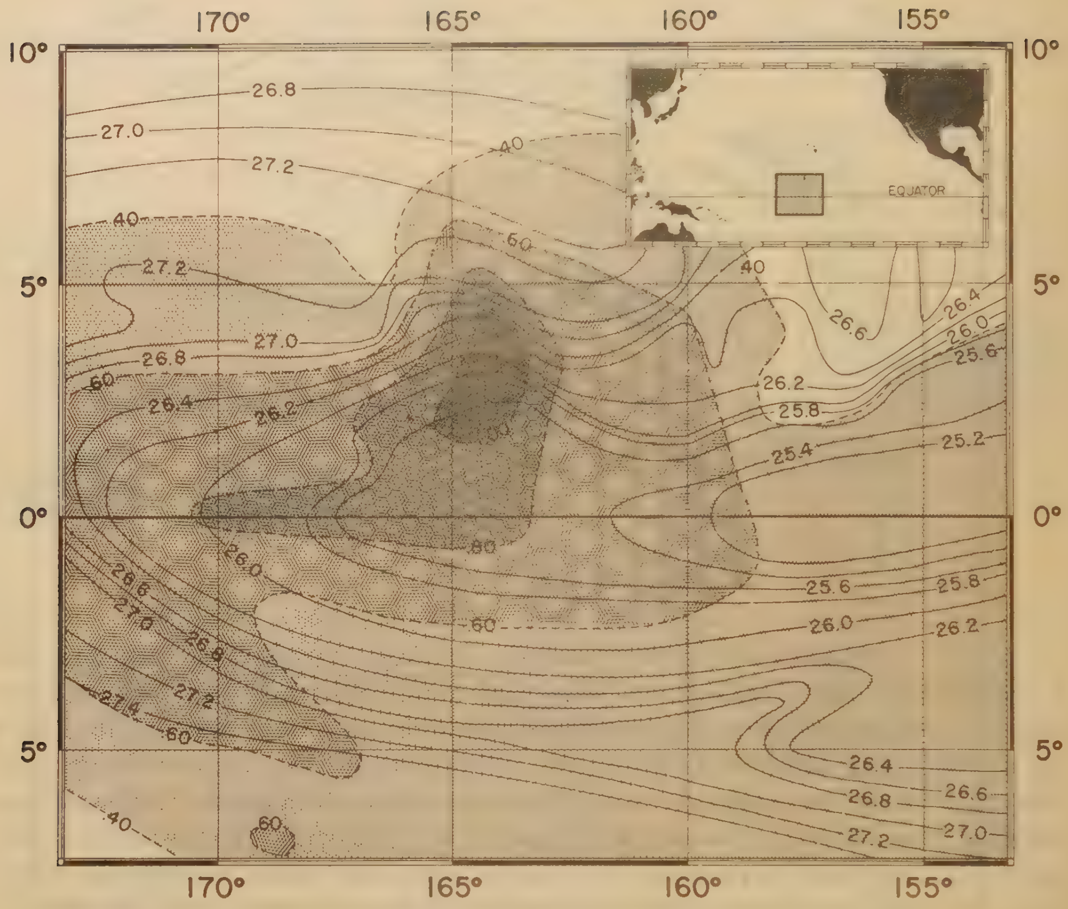

Figure 3. Surface Temperature and Phosphate. This oceanographic production line does not run steadily. In this picture we see evidence of a spurt at the beginning of the chain of events. The lines follow equal temperatures and the shading indicates the variation in nutrients (phosphate). The tongue of cold water can be seen along with the dark shading indicating masses of high nutrient waters. Such masses of enriched water are of primary interest since the genesis of the abundance of tuna must be related to them. Strong winds have given a push to the circulation system and we think that this will soon be followed by an extra good concentration of tuna. We have no idea how many days or how many miles separate the push of the wind from the bunching of the tuna, but figure 8 proves such bunching of the tuna does occur.

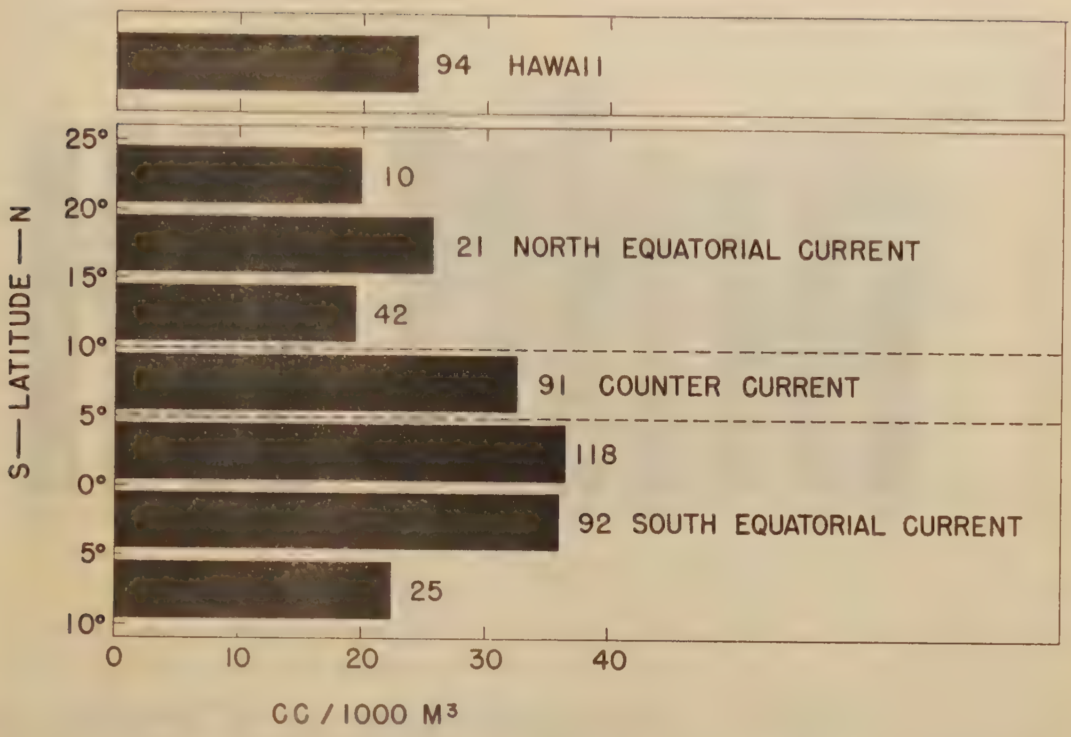

Figure 4. Zooplankton Abundance by Latitude. Since the waters immediately north and south of the Equator contain enriched subsurface water, it is interesting to note that zooplankton, which must have a rich "pasturage" to thrive, is particularly abundant near the Equator. The amount of zooplankton at various latitudes both north and south of the Equator is shown in the bar diagram above. The numbers at the end of the bars indicate number of net hauls made for each of the latitude categories. The longer bars near the Equator indicate greater amounts of zooplankton; the top bar, representing waters around Hawaii, suggests that the Island waters may be less productive than equatorial waters.

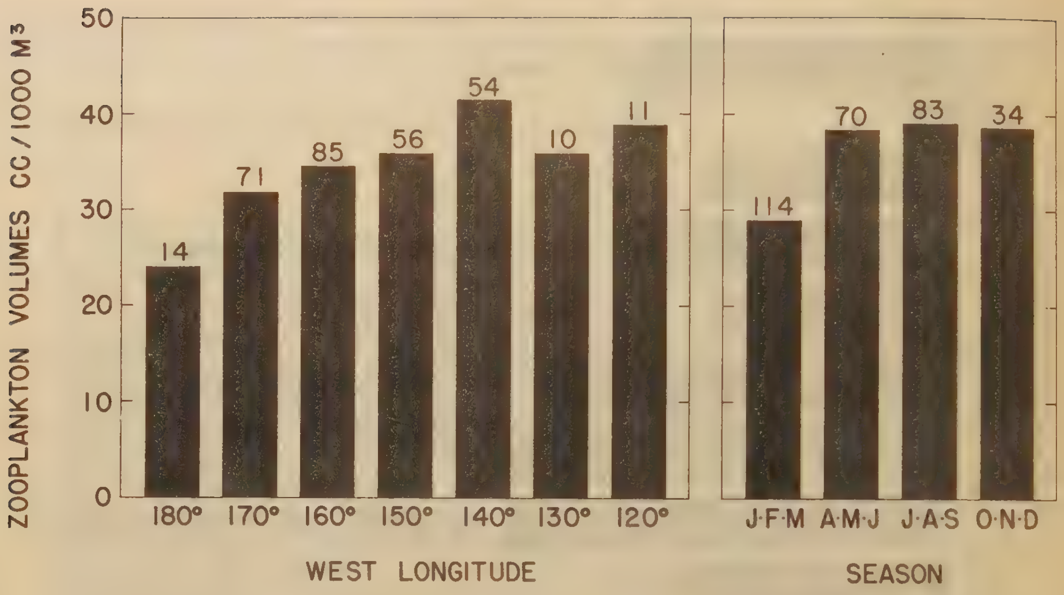

Figure 5. Zooplankton Abundance by Longitude and Seasons. We think that the productivity at the Equator increases from west to east. The diagram at the left confirms this at least between 180° and 140° W. longitude. It appears that plankton production levels off in the eastern sector of our survey area, but our surveys east of 140° W. have not been comprehensive enough to be sure of this.

The diagram to the right shows that some parts of the year are more productive than others. We expect that further analyses will show that these changes in productivity are related to the fluctuation in tuna abundance.

While plankton is an important indicator of richness, most plankton animals are too small for tuna food. Instead they are fodder for the small fish and squid which in turn are eaten by the tuna.

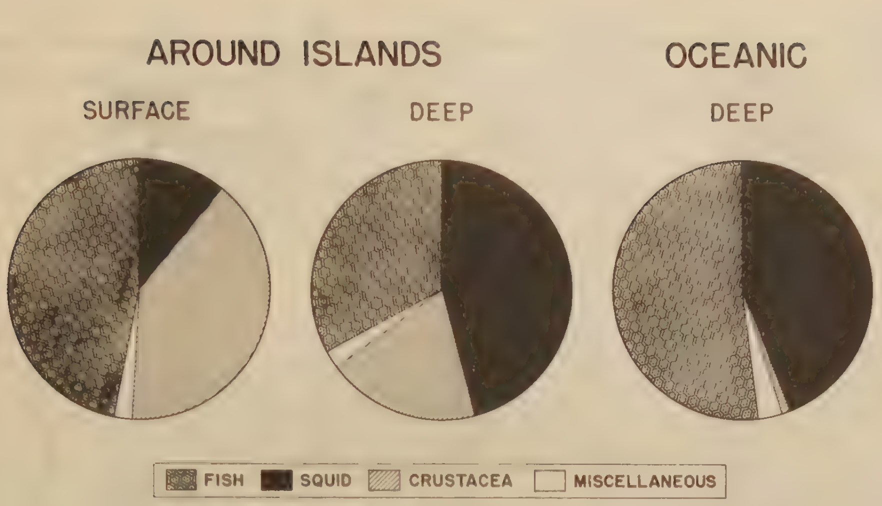

Figure 6. Food of Yellowfin Tuna. To find out what the tuna eat we have identified the material in the stomachs of many tuna caught on our fishing surveys. Apparently yellowfin tuna eat almost anything they encounter that is active, large enough to be noticed, and small enough to swallow. The variety of sea animals in their diet is outstanding and many are of surprisingly small size. Over 75% of the stomachs contained organisms weighing less than one-tenth of an ounce. Occasionally quite large animals are eaten too, the largest being a 16-inch skipjack found in the stomach of a 53-inch yellowfin. This simplifies the problem of finding their feeding grounds. They should be anywhere in warmer waters where general biological productivity is high. There is no need to find concentrations of a particular kind of feed.

Consistent with this are the different proportions of the various kinds of food in tuna taken from island and oceanic areas. Within 5 miles of islands the surface tuna eat almost equal parts of small reef fish and crustaceans such as the free-swimming young stages of crabs and mantis shrimp, which in their adult form live on the reef and on the bottom in shoal water. Somewhat farther offshore but still within 10 miles the crustaceans diminish and the squids become a much larger element in the food of deep-swimming tuna caught with longlines, and in truly oceanic areas the diet is made up of almost equal parts of small fish and squid with very few crustaceans.

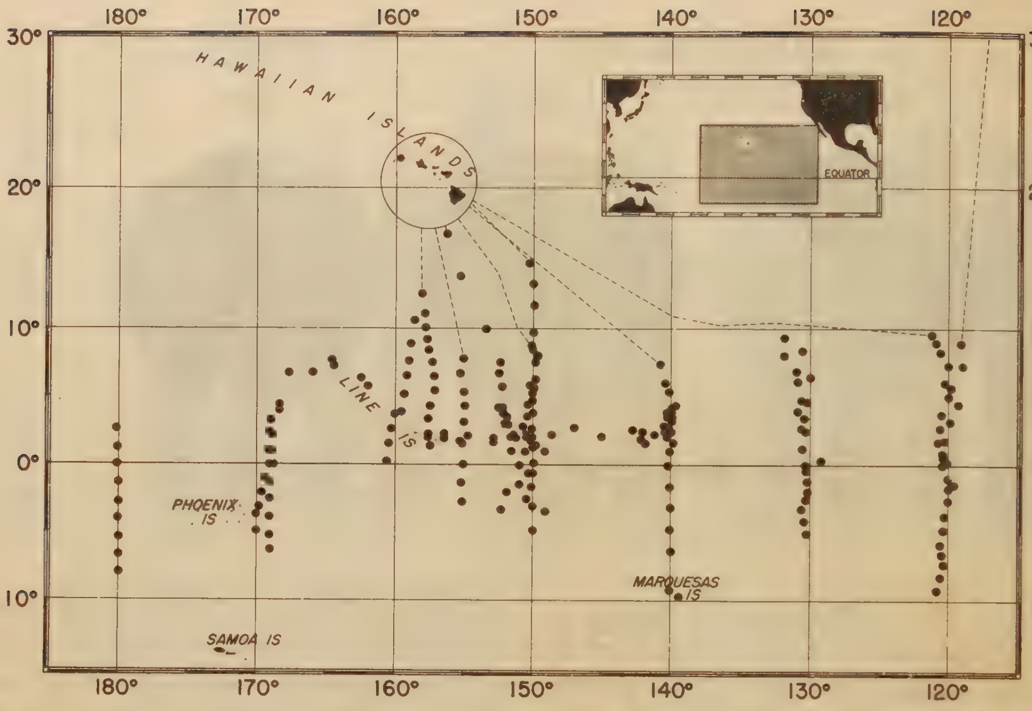
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Figure 7. Equatorial Longline Fishing Cruises. After finding a rich zone near the Equator south of Hawaii, we fished this area using the Japanese longline method. We have tried to cover a broad expanse of the equatorial region, as can be seen from the above chart. Our plan was to fish across the Equator on selected longitudes at various times of the year and in about another year we will have completed this phase of the program. From our longline station data, the positions of these stations being indicated by the black dots, we detect quite drastic changes in tuna abundance and we plan to relate these fluctuations to the hydrographic conditions and information about the fish food and, finally, attempt to predict the best time and place to fish.

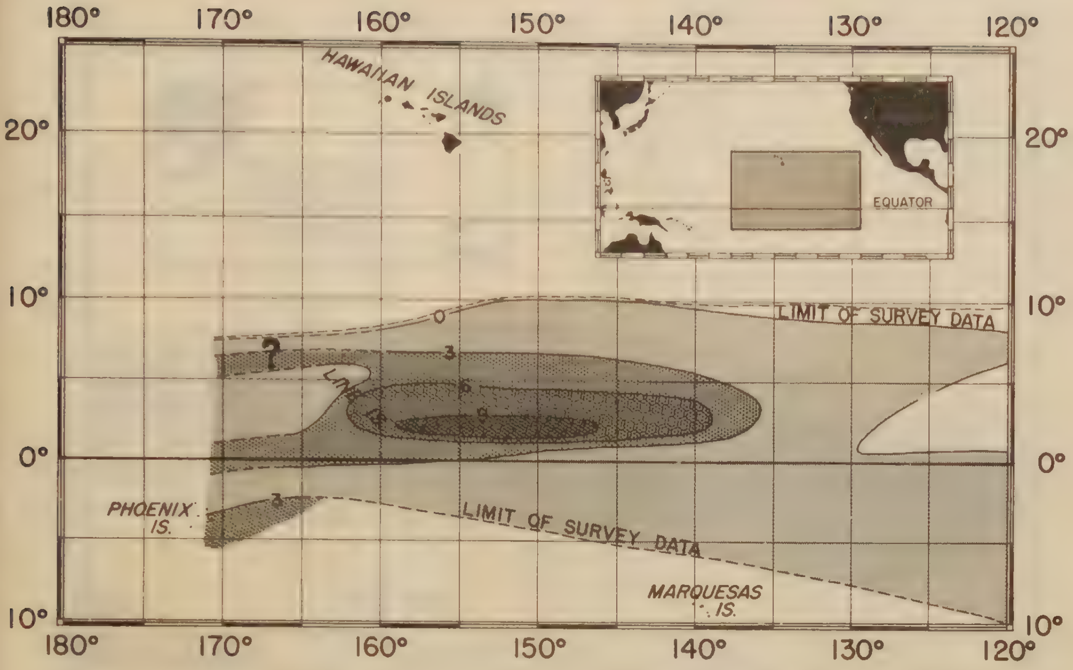
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Figure 8. Yellowfin Tuna Catch/100 Hooks (July-November). As mentioned previously, we do not yet have enough crossings to plot the distribution for all times of the year. However, when we group together a set of 10 crossings made in August, September, October, and November (of three different years), we can draw a very generalized picture of the concentration in terms of number of yellowfin tuna caught per hundred hooks per day. We have drawn lines through equal catches. The "9-line" encloses the area yielding 9 or more yellowfin per hundred hooks; between the 9-line and the 6-line the catches averaged 7 to 8 per hundred hooks, etc. You can see that at 150° W. longitude the fishing was best in a zone centering at about 2° N. latitude running east to about 145° W. longitude and west to 160° W. longitude. It tapers off rapidly going north or south and more gradually going east or west.

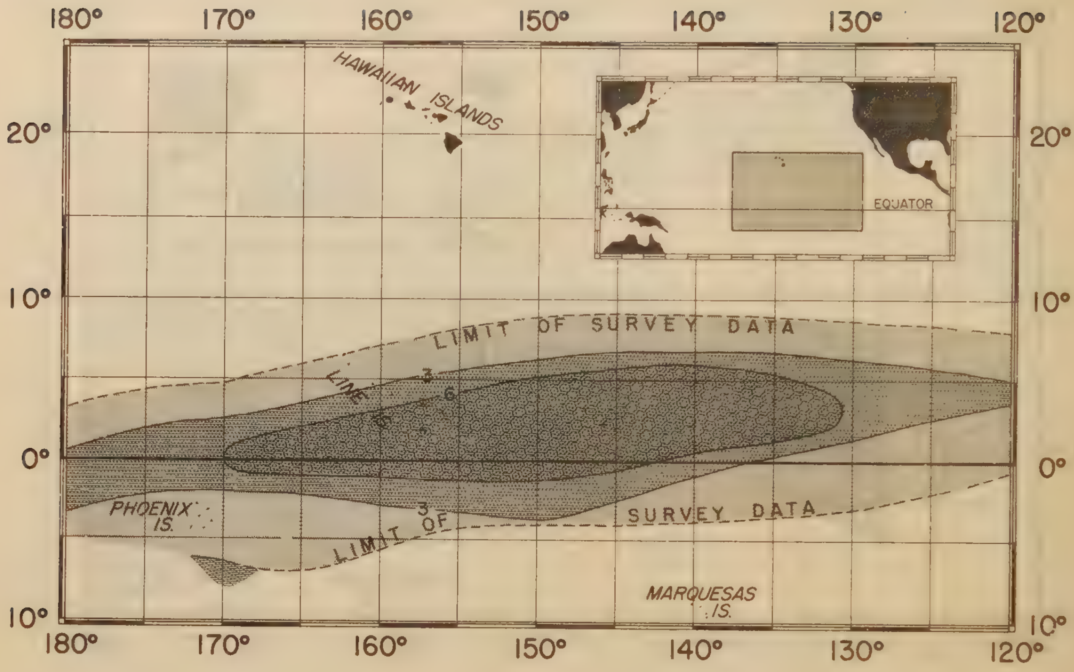


Figure 9. Yellowfin Tuna Catch/100 Hooks (January-June). Another group of four fishing sections in February, March, May, and June suggests a wider spread of medium concentrations and no really high concentrations of yellowfin tuna. Otherwise the pattern is very much the same. We do not consider the above or the previous chart as being very accurate. Too many different months are grouped together and there are not enough repeated fishing trials for the same months. Until our survey plan is completed, these should only be regarded as tentatively describing the distribution. Even so, it is becoming clear that certain areas along the tuna-rich equatorial belt contain more tuna than others and during some periods of the year the tuna are more concentrated.

Translating these concentrations in to commercial fishing yields, a vessel fishing on the grounds that average 6 tuna per hundred hooks would catch 180 tons per month, if it fished the same amount of gear (2,000 hooks) as is normally operated by Japanese longline vessels. But without lavish use of manpower, it is difficult to handle daily this much gear. The American vessel shown in figure 17 set less than 500 hooks per day.

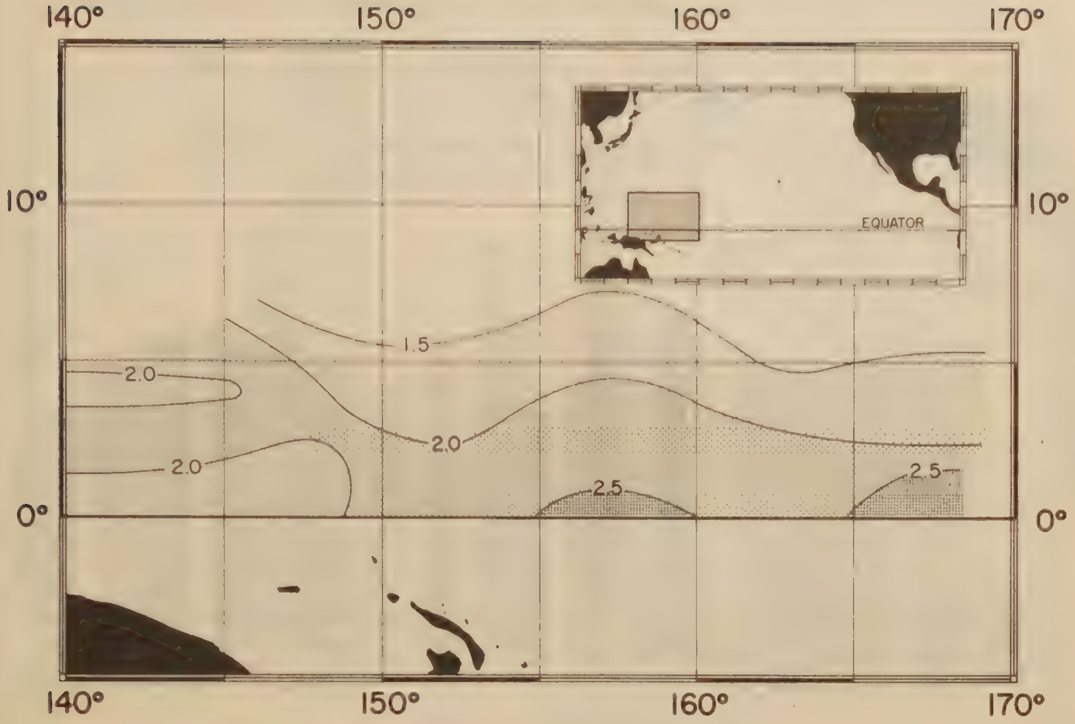


Figure 10. Relative Abundance of Yellowfin Tuna in the Western Equatorial Pacific. To obtain information on the distribution of yellowfin tuna throughout the Pacific Ocean, we have obtained data from the nine Japanese mothership expeditions to the western equatorial Pacific in 1950 and 1951. These fishing trials were restricted by SCAP to the area from 130° to 180° E. longitude and from the Equator to 24° N. latitude. Our observers went along on five of the expeditions to collect biological data and production records.

This figure gives the catch rates as averages for yellowfin tuna from all expeditions. The contour lines in the figure separate zones of like catch rates. The Japanese fishing in the western Pacific agrees with POFI's in the central Pacific by showing yellowfin to be most abundant near the Equator and tapering down to the north; however, the abundance is very much lower. The best western areas produced only 2.5 yellowfin per hundred hooks whereas the best areas in the central Pacific produced over 9 and there was a very large area that averaged 6 fish per hundred hooks.

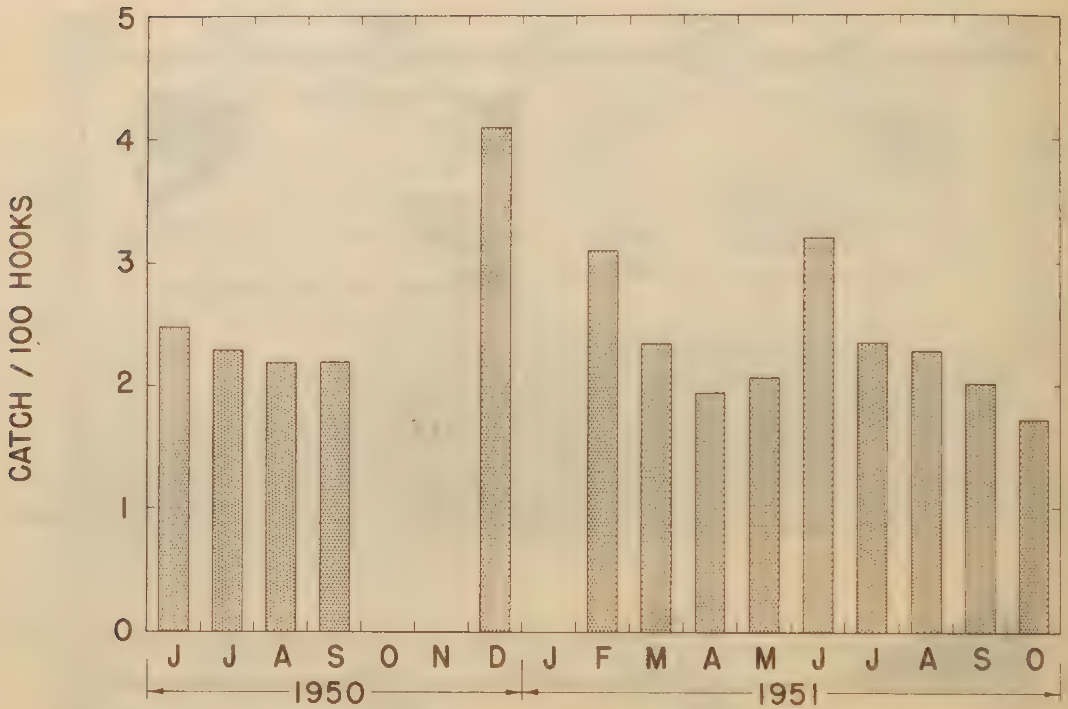


Figure 11. Seasonal Fluctuations in the Longline Catch Rate in the Western Pacific. It is of interest to know the times of the year when the Japanese mothership expeditions experienced the best fishing. The above diagram shows how the catch varied from month to month during 5 months of 1950 and 9 months of 1951. There appear to be two peaks of abundance in this western region; one in midwinter and one in midsummer. The fluctuations in the monthly catch rates are of much smaller magnitude than generally experienced in temperate zone fisheries and there is no month when the catch sags as low as one-third of the peak value. In this instance the average rate of capture by the Japanese was between two and three yellowfin per 100 hooks in most months.

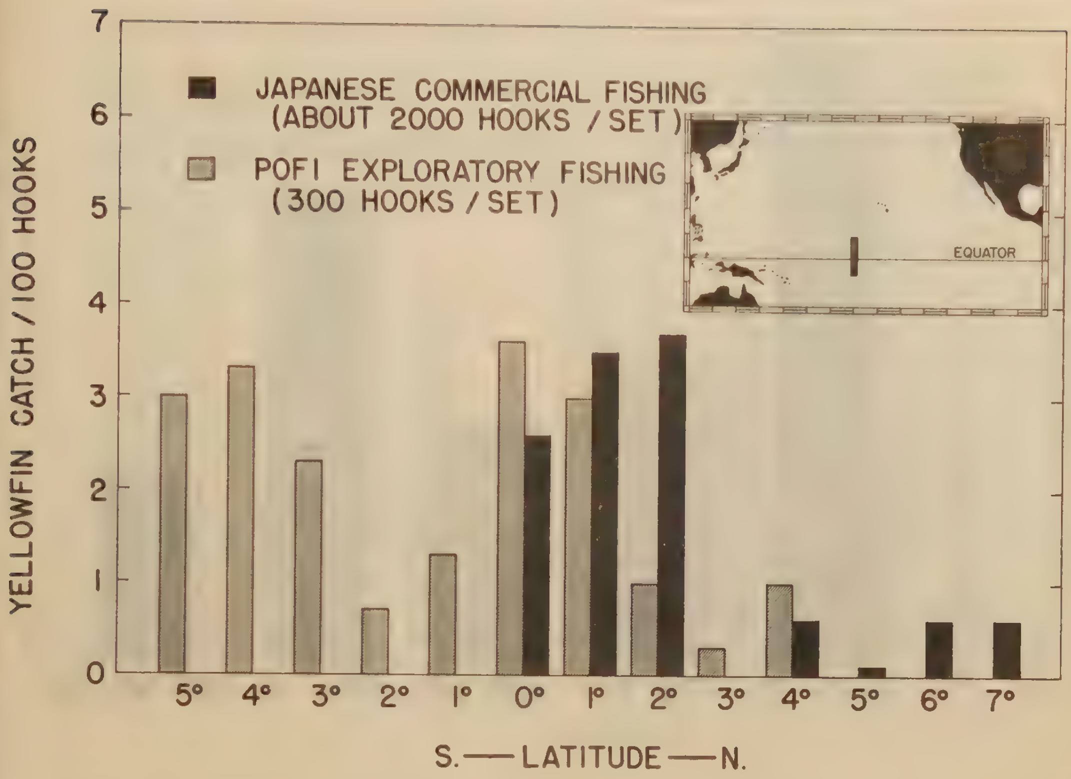


Figure 12. Comparison of Catch Rates from Japanese Commercial and POFI Experimental Fishing. In the two previous figures we discussed the catch rate from Japanese longline fishing in the western Pacific. Until recently we did not know definitely whether our small-scale experimental fishing was sufficiently like the Japanese full-scale commercial fishing to give the same measure of yellowfin concentration. In 1952 we had a chance to make a direct comparison when the JOHN R. MANNING and a Japanese vessel were fishing at nearly the same time in the same place, near the western boundary of our survey area (along 170° W. longitude). Plotting the catch per hundred hooks of each vessel against latitude shows that our gear gives catching rates that are comparable to the Japanese commercial operations.

This is the first instance of Japanese fishing as far east as our survey area. There is no evidence that they have come as far as the relatively richer area south of Hawaii.

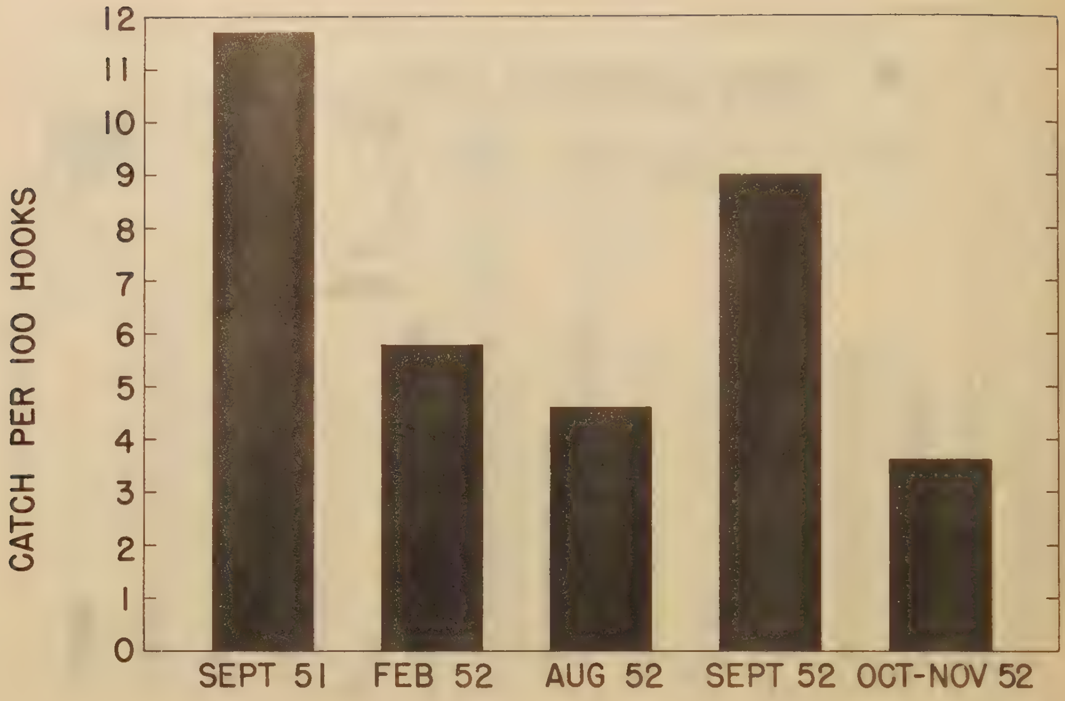


Figure 13. Abundance of Yellowfin at 150° W. Longitude on Successive Cruises. While the results of succeeding fishing surveys are consistent in most respects and show the same rich zone near the Equator, some of the details are puzzling. Here we have grouped the results of successive surveys along 150° and 155° W. longitude. You can see that a downward trend in catch rate is suggested and superimposed on this are fluctuations from one cruise to another. These fluctuations may be the result of the spurts and halts in the oceanographic production line mentioned a few pages back. It is less easy to see why there should be a downward trend. The fish of the more recent trips, however, have been larger as well as fewer and we may be witnessing the passing of a successful year class. If so, the numbers should go up again with another successful spawning. We are hopeful that studies of a biological nature, such as those related to larval abundance and distribution, may yield clues concerning these fluctuations.

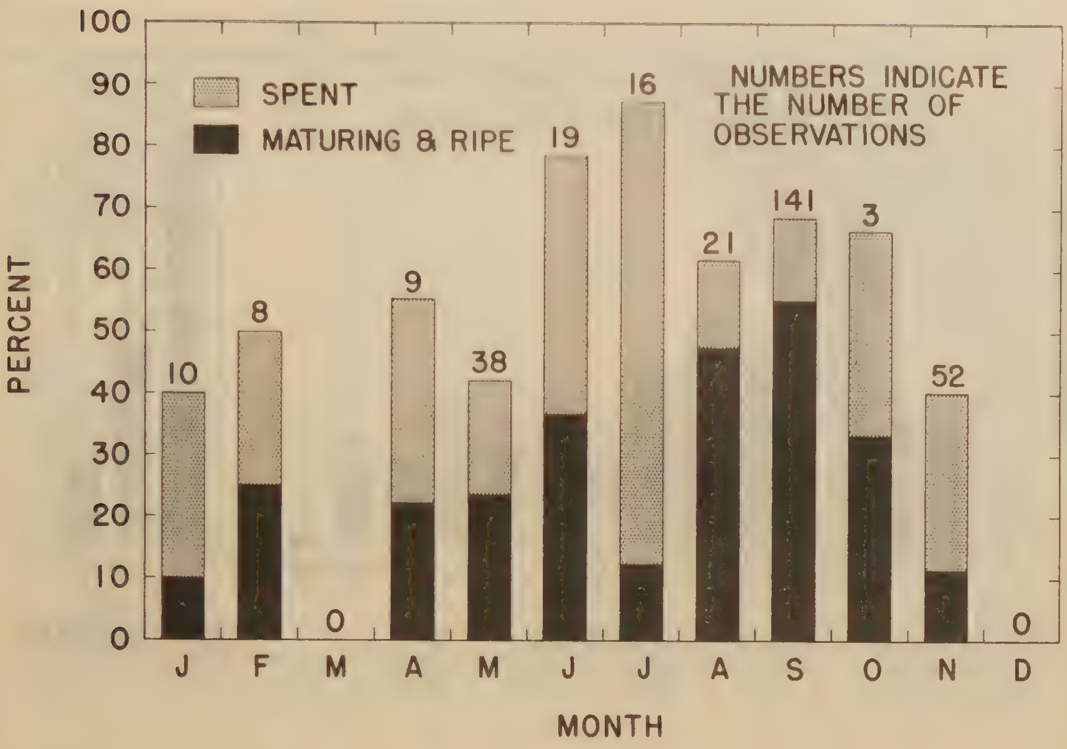


Figure 14. Tuna Spawning Near the Equator. In addition to knowledge of the abundance of yellowfin tuna in the central Pacific it is essential to understand the distribution of the different populations found throughout the Pacific. One method of accomplishing this is to study the spawning habits of tuna found near the Equator. We have examined the roes in a large number of the yellowfin captured during our fishing trips. A high percentage of these fish caught during all months sampled were either nearly ready to spawn or were spent. Somewhat more spawning activity is suggested during the summer and fall months than at any other time of the year, but some spawning yellowfin were obviously present throughout the year.

Although the condition of the roe proves that the yellowfin would spawn in the near future or had done so in the recent past, very few actually running ripe fish are caught. This leaves some doubt as to the exact spawning place. Much of this doubt is removed by our finding the very young tuna larvae in our plankton hauls from the equatorial area.

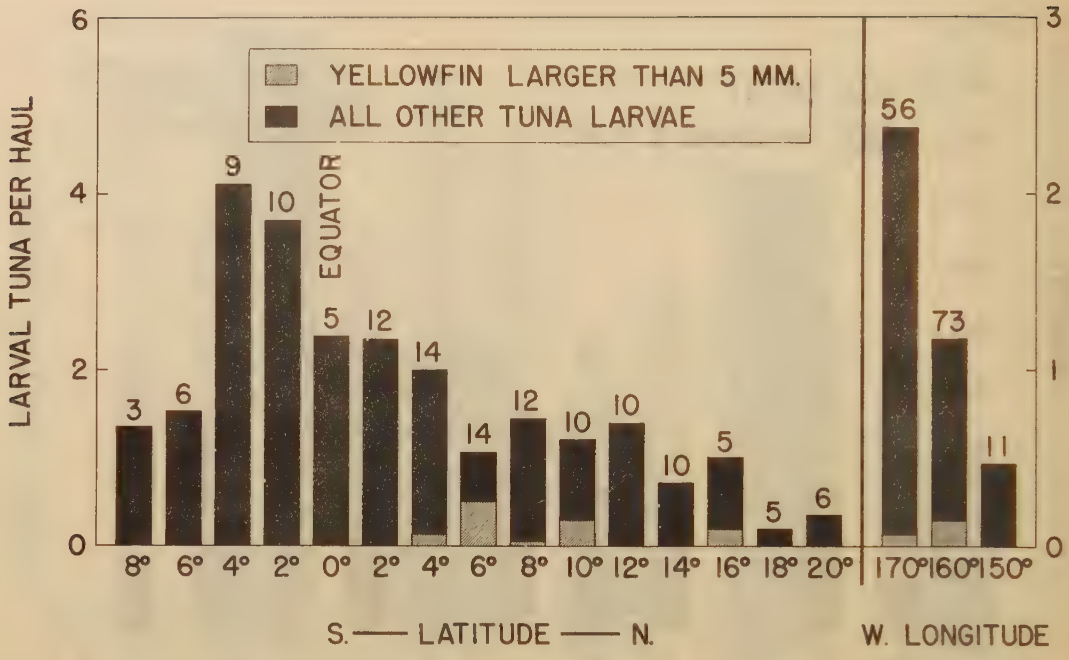


Figure 15. Distribution of Tuna Larvae in Central Pacific. Counts of the number of tuna larvae in a portion of our plankton samples show them to be most numerous in the hauls taken near the Equator, not far from the places in which we found the near-ripe and the recently spent females. Regrettably too few of our hauls have been sorted for larvae to give a reliable distribution diagram. Also, it is difficult to tell the different kinds tuna apart when they are smaller than 5 millimeters (one-fifth of an inch) long. This leaves the definite yellowfin larvae records quite scanty and the indication of more larvae at 170° than at 150° W. longitude must be taken with reservation. However, these very preliminary results give hope that the work on planktonic larvae, as it progresses, will indicate whether the tuna spawn over the entire east-west range of adults or whether spawning is concentrated in one or more separated localities. This bears on the question: Does the Pacific have one large interbreeding stock of tuna or a number of separate self-perpetuating stocks?

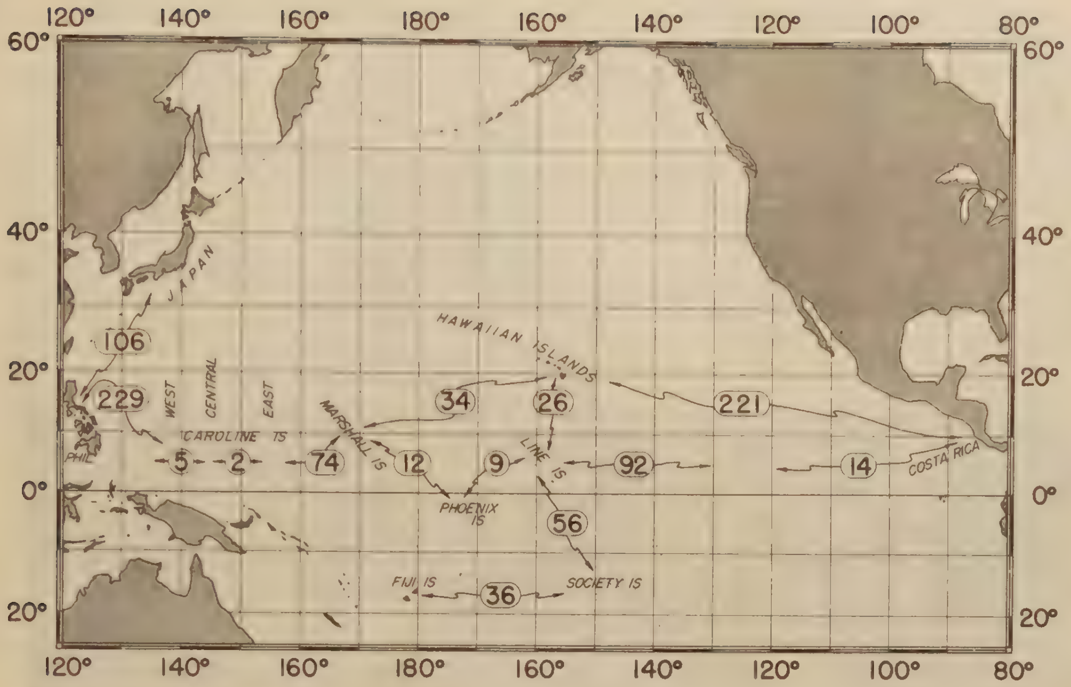

120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
JAPAN
PHIL
WEST
CENTRAL
EAST
CAROLINE IS
MARSHALL IS
HAWAIIAN ISLANDS
LINE IS
PHOENIX IS
FIJI IS
SOCIETY IS
COSTA RICA
106
229
5
2
74
12
34
9
26
92
221
14
56
36

Figure 16. Index to Racial Difference of Yellowfin Between Sample Localities. To understand the relationship between tuna stocks we have compared the body proportions of yellowfin tuna from various parts of the Pacific. When the differences in body proportions between two samples is great, the index number appearing on the above chart is large, and when the tuna from the two sample areas are similar, the numbers are small. This analysis shows that west coast yellowfin differ widely from those of the central Pacific, and that the yellowfin of the central Pacific differ considerably from those farther west toward Asia. Unfortunately no one knows how large an index number is required to prove complete separation of stocks or conversely how small it should be when there is complete mixing. Firm conclusions require evidence from other sources.

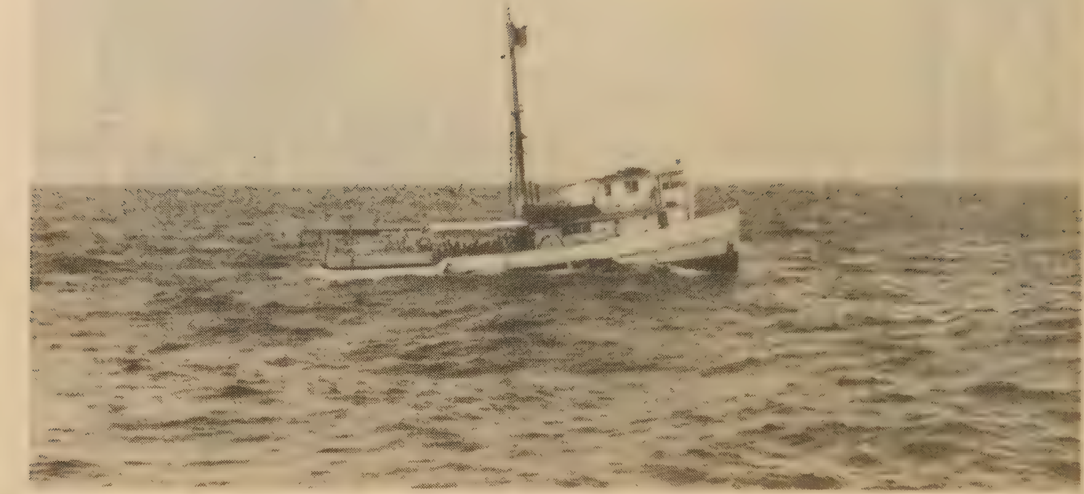


Figure 17. Equatorial Commercial Fishing. To test the commercial possibilities of the equatorial region, we chartered the West Coast purse seiner, CAVALIERI, to fish on a semi-commercial basis with longline gear in the equatorial Pacific. Although a catch of only 48 tons of tuna was realized in 33 days of fishing, we learned that the west coast purse seine boat is readily adaptable to longlining. It was also evident from this trial that at least twice the gear must be fished if we expect an American vessel to profit from such a venture. This will probably require improvements in the design of the gear and increased mechanization in setting and hauling.

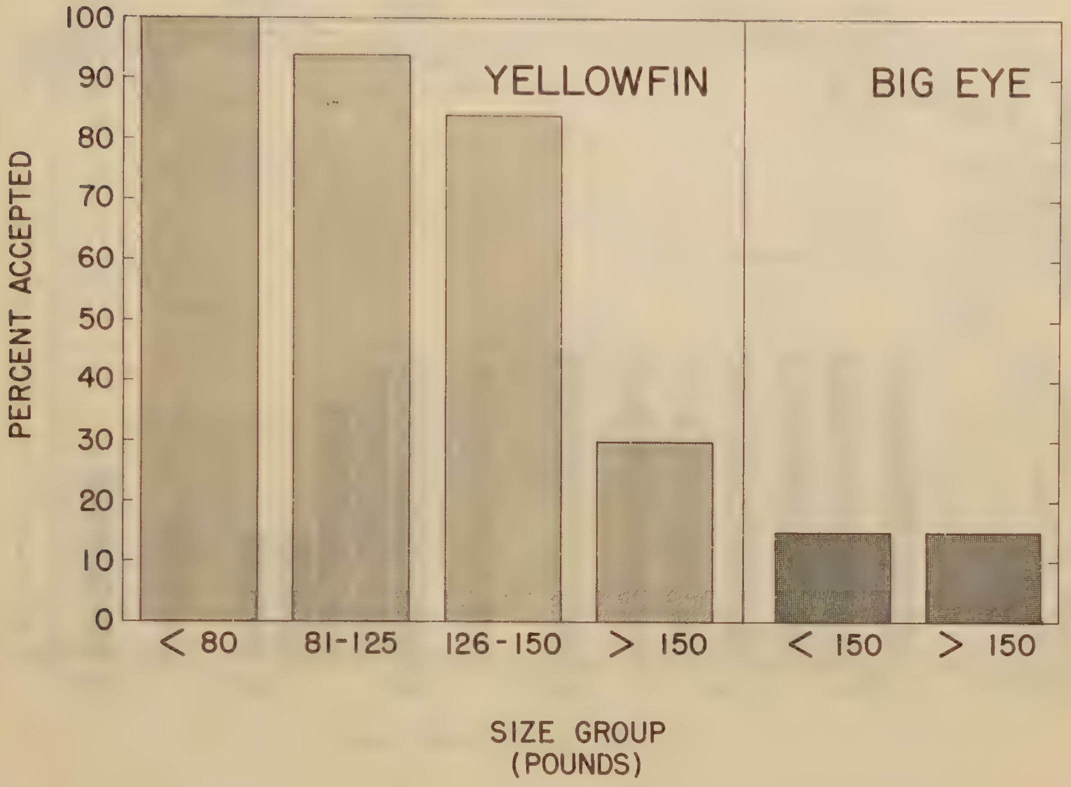


Figure 18. Acceptance of CAVALIERI Longline Tuna for Canning. Since the CAVALIERI catch of tuna consisted of large fish from an untried area, we were vitally interested in the percentage acceptance by the cannery. The above figure shows that a very small percentage of the small and medium sized fish were rejected by the cannery, while only 30 per cent of the yellowfin tuna above 150 pounds were acceptable. The rejection at the cannery was primarily on the basis of the color of the flesh, the larger fish being generally darker than the smaller. Later observations of fish of various sizes canned especially for us indicated that flavor was not noticeably affected by size.

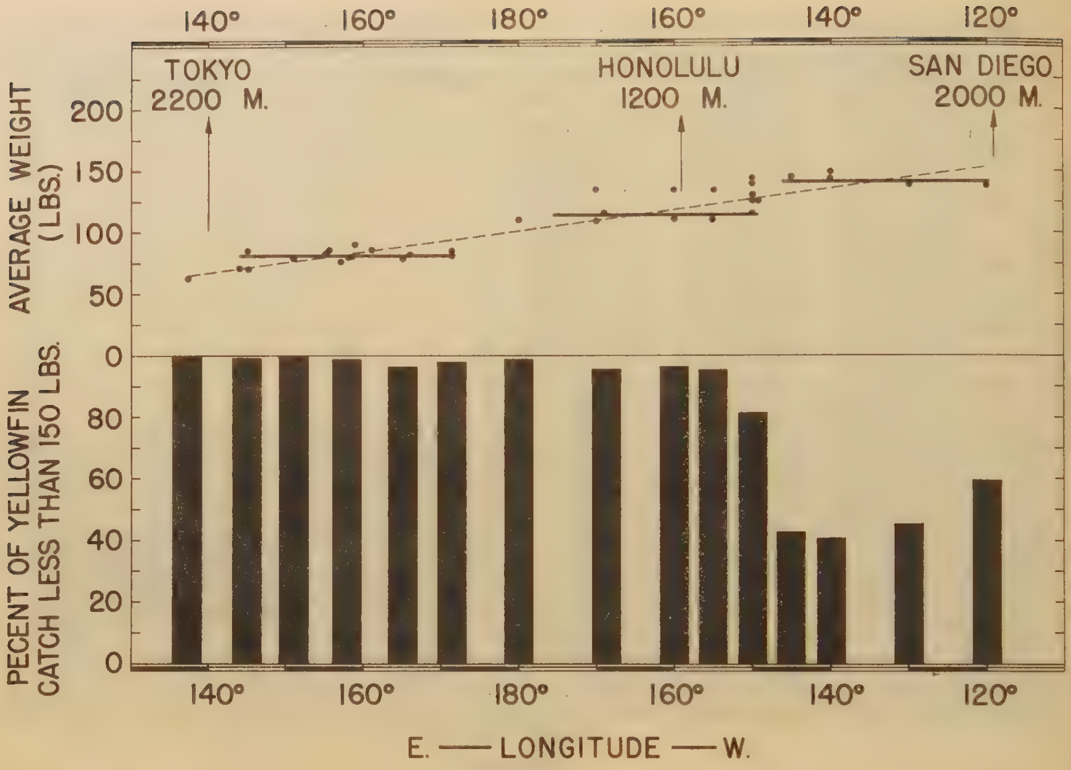


Figure 19. Variation in Size of Yellowfin Along the Equator. The commercial venture stressed the importance of increasing our knowledge of the distribution of tuna with respect to size. The upper panel shows the change in size of the yellowfin along a 6,000-mile stretch of the equatorial Pacific. To the west of 180° each point represents a sample taken by POFI observers while on board Japanese motherships, while to the east of 180°, the measurements are from POFI catches. The size appears to increase in steps rather than in a steady progression and there is an indication that the tuna are smaller east of 140° W.

The lower panel shows the percentage of fish that weighed less than 150 pounds. Since a size of about 150 pounds is the upper limit for having most of the catch accepted under the "light meat" canning label, it is of interest to note that most of the yellowfin caught west of 140° W. longitude have been under 150 pounds.

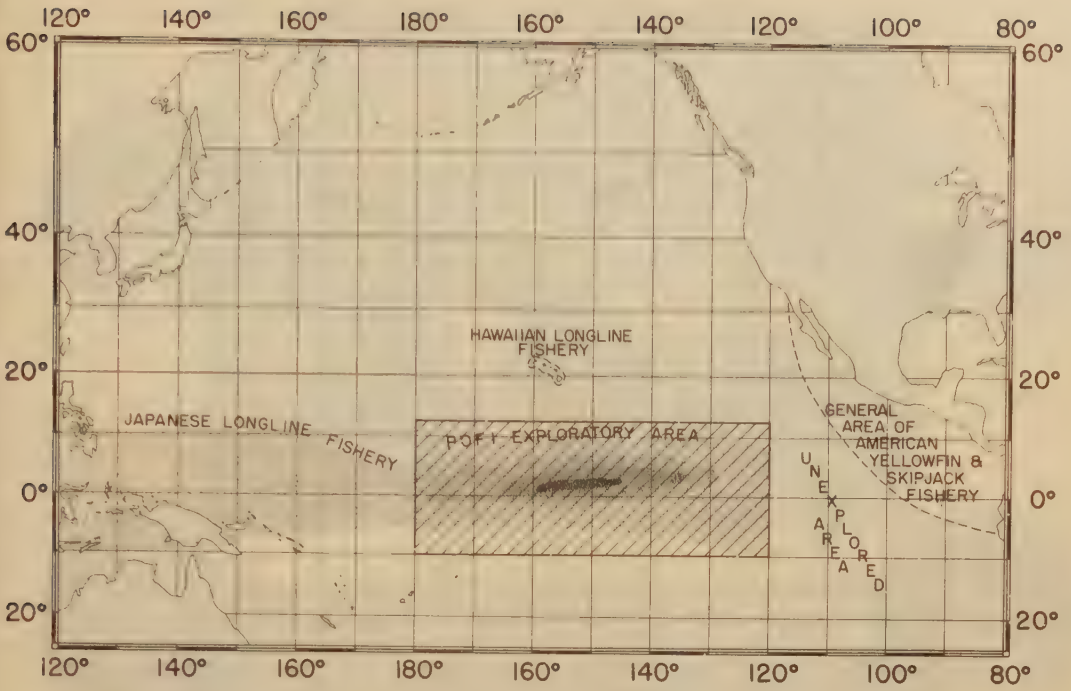
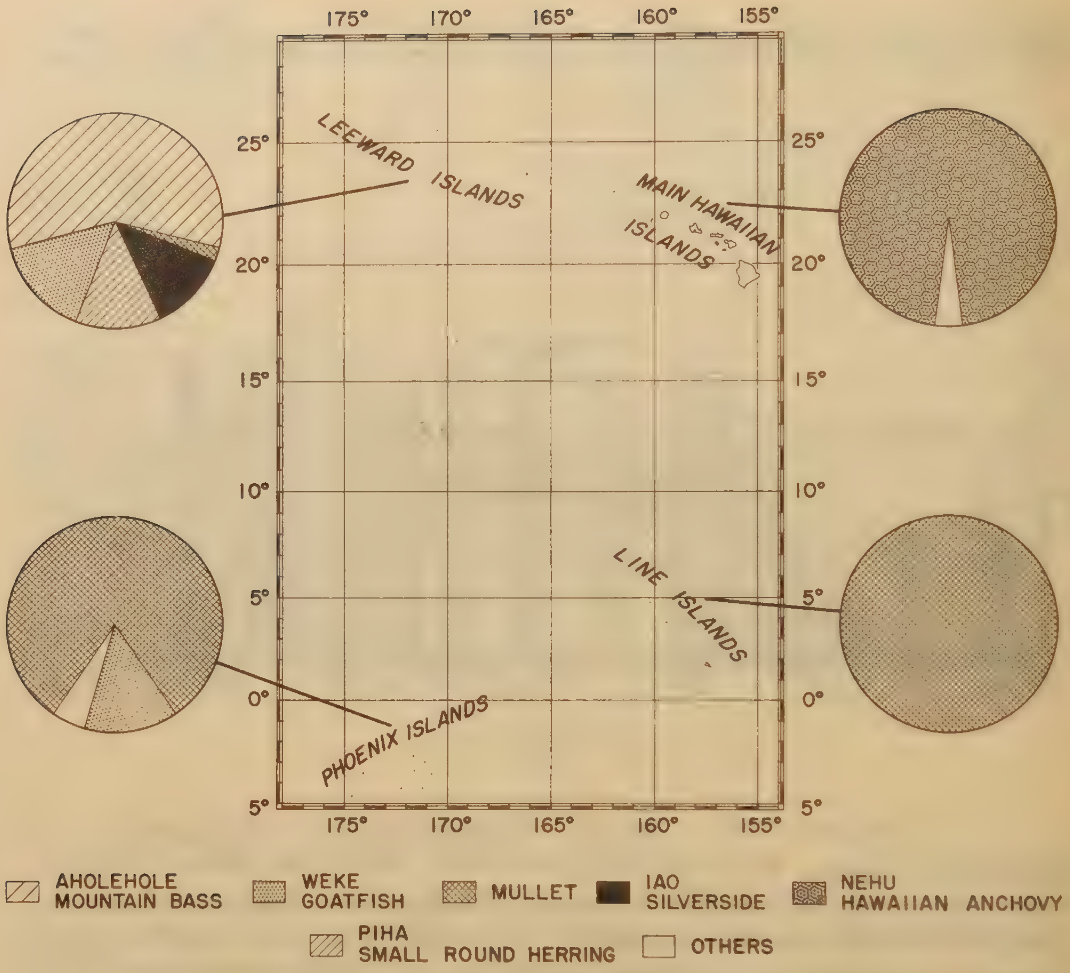

120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
HAWAIIAN LONGLINE FISHERY
JAPANESE LONGLINE FISHERY
POFI EXPLORATORY AREA
GENERAL AREA OF AMERICAN YELLOWFIN & SKIPJACK FISHERY
UNEXPLORED AREA

Figure 20. Known Trans-Pacific Distribution of Yellowfin Tuna. Summarizing all our yellowfin data collected since the start of the POFI equatorial longline fishing and adding other data from various sources, we constructed the above chart. It appears quite certain that abundant yellowfin stocks are to be found continuously across the Pacific from 120° W. to the Asiatic mainland with the greatest concentration in the broad band south of Hawaii between 140° W. and 170° W. No catch records are presently available for the 1,500-mile stretch between 120° W. and the Galapagos. We do not know yet whether the band of tuna is continuous through the area designated as "unexplored" in the above figure.



175°
170°
165°
160°
155°
25°
20°
15°
10°
5°
0°
5°
LEEWARD ISLANDS
MAIN HAWAIIAN ISLANDS
LINE ISLANDS
PHOENIX ISLANDS
AHOLEHOLE MOUNTAIN BASS
WEKE GOATFISH
MULLET
IAO SILVERSIDE
NEHU HAWAIIAN ANCHOVY
PIHA SMALL ROUND HERRING
OTHERS

Figure 21. Bait Resources in the Central Pacific. Extensive bait surveys have been made in most of the island possessions of the United States in the central Pacific to determine the availability of live bait. The Hawaiian anchovy, the nehu, is the major bait species used in the Hawaiian Islands. The available supply is inadequate for local fleet of tuna sampans. In the leeward Hawaiian Islands bait can be found in moderate quantities at certain times of the year. The kinds are aholehole, iao, piha, weke, and some mullet. However, these were not found consistently and there probably is not enough to supply more than a small fleet of sampans. In the Line and Phoenix islands the major bait species is young mullet. A few weke, pronounced "vecky", are also there. Despite their considerable lagoon areas, these islands probably can supply only a small fleet of sampans during part of the year.

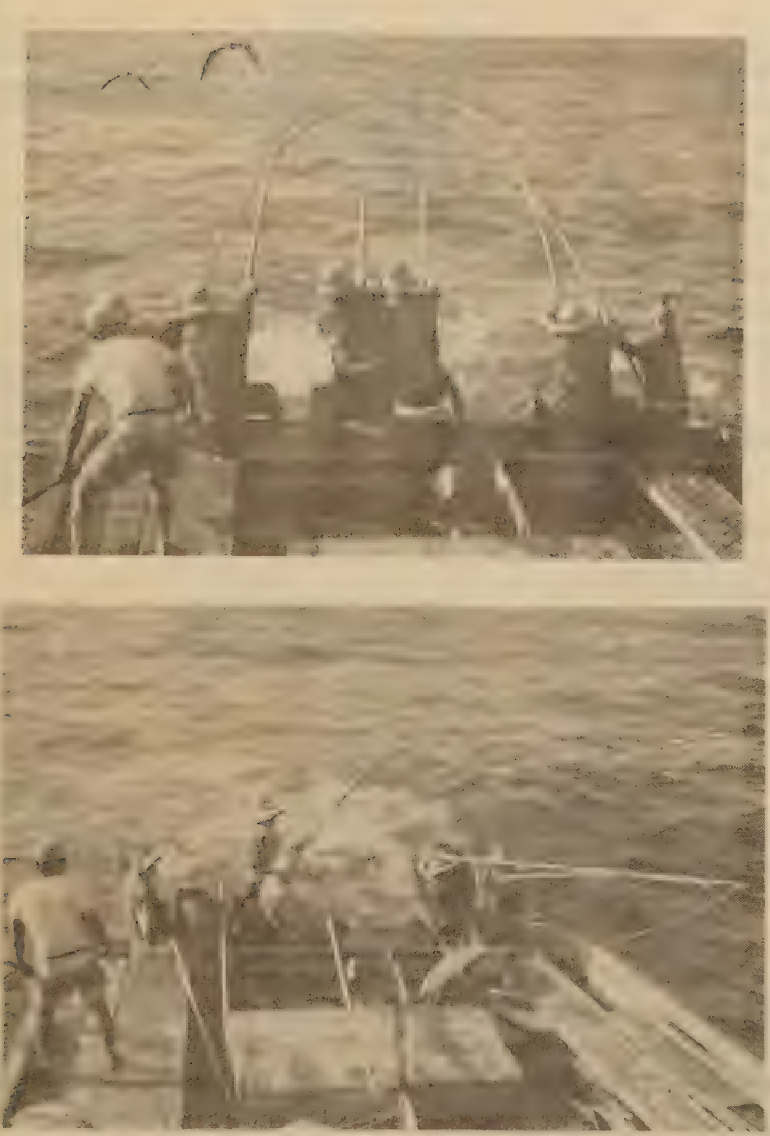


Figure 22. Midwinter Sampan Fishing in Line Islands. One trial venture to the Line Islands made by the Honolulu based sampan, TRADEWIND, was logistically supported by the HUGH M. SMITH, and fished the Line Islands area near the Equator south of Hawaii during January. This effort was the first commercial attempt to capitalize on the results of POFI live bait fishing surveys made during 1950 and 1951. In spite of a mediocre catch of 14 tons of yellowfin and about 2 tons of reef fish, the fishermen from the sampan felt that a profitable off-season fishery might be developed. The photos show TRADEWIND fishermen catching a large 6-pole yellowfin; the average size of the tuna caught by the TRADEWIND on this trip was 40 pounds (1- and 2-pole fish), considerably smaller than those taken by longline gear in that region.

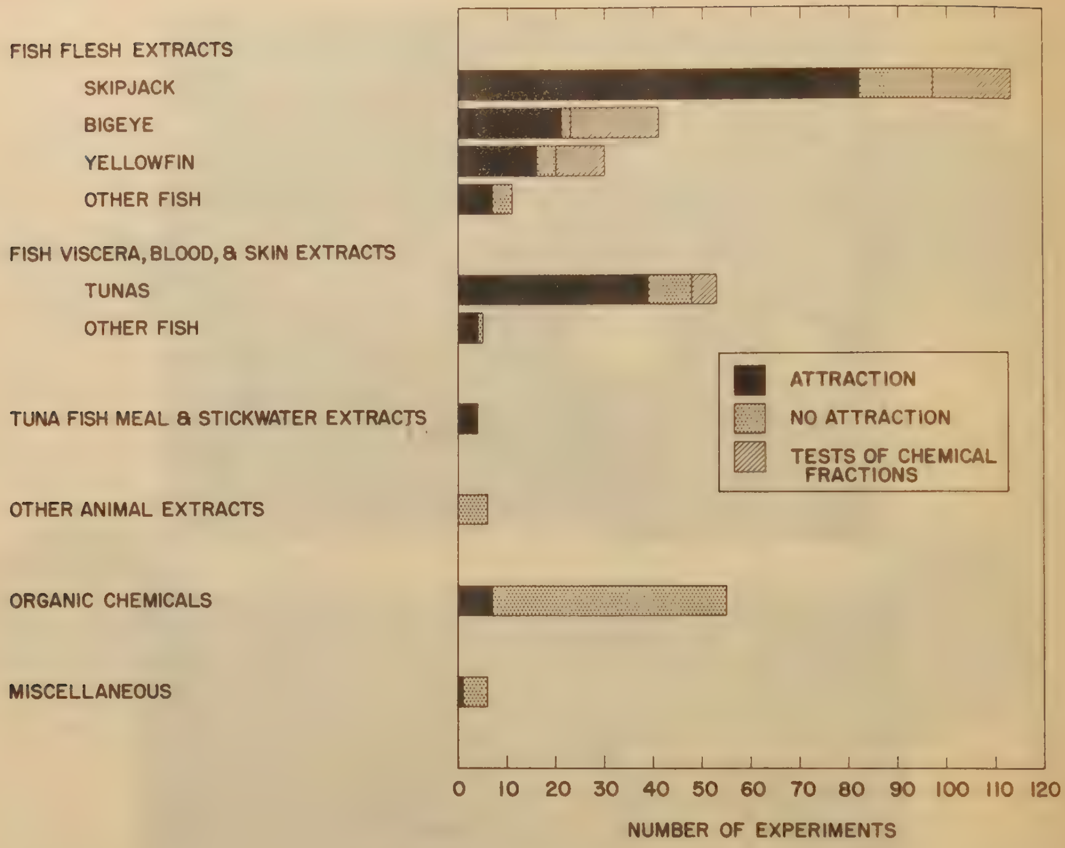


Figure 23. Search for Bait Substitutes. A major project of our laboratory is a search for live bait substitutes. Rather than trying various things in hit-or-miss fashion, we have been making controlled experiments on tuna held in a pond at the University of Hawaii Marine Laboratory at Coconut Island to find out whether they use sight, taste, smell, hearing, or combinations thereof, to locate food. In 1951 we found that tuna were sensitive to extracts made from the tissues of fish. In 1952 the taste-smell experiments were extensive as shown in the above chart. Early in 1953 we began to test the extracts on tuna schools out at sea. Results have been disappointing. It probably will be necessary to combine visual and chemical stimuli to attract and hold the fish near the stern of the vessel for pole and line fishing.

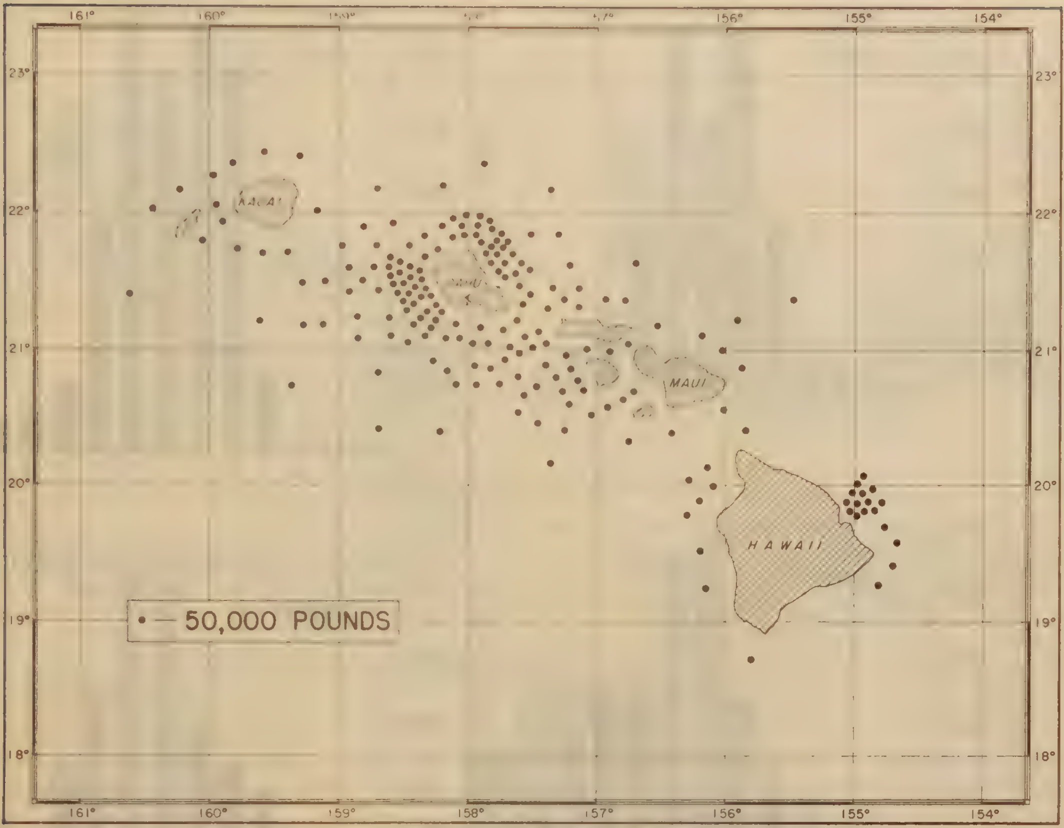


Figure 24. Distribution of Skipjack Catch Around the Hawaiian Islands. Skipjack form the basis for the principal fishery of the Hawaiian Islands. We are studying the distribution of skipjack in the Hawaiian area to ascertain whether or not the skipjack are confined to the immediate vicinity or whether there are worthwhile concentrations beyond the limits of present fishing. The above figure shows the location of the skipjack fishery during the 5 years, 1948 to 1952. The concentration of dots northeast of Oahu is near the major live bait source in Kaneohe Bay, the concentration southwest of Oahu is near the major landing port of Honolulu, and the cluster of dots northeast of the island of Hawaii is just outside of the port of Hilo where a small fleet is locally based. It is obvious that the present fishing is concentrated near the ports and near major baiting areas. This suggests that the fishery is limited by the range of the fishing boats rather than the range of the skipjack. As already noted the catch is also limited by the scarcity of bait.

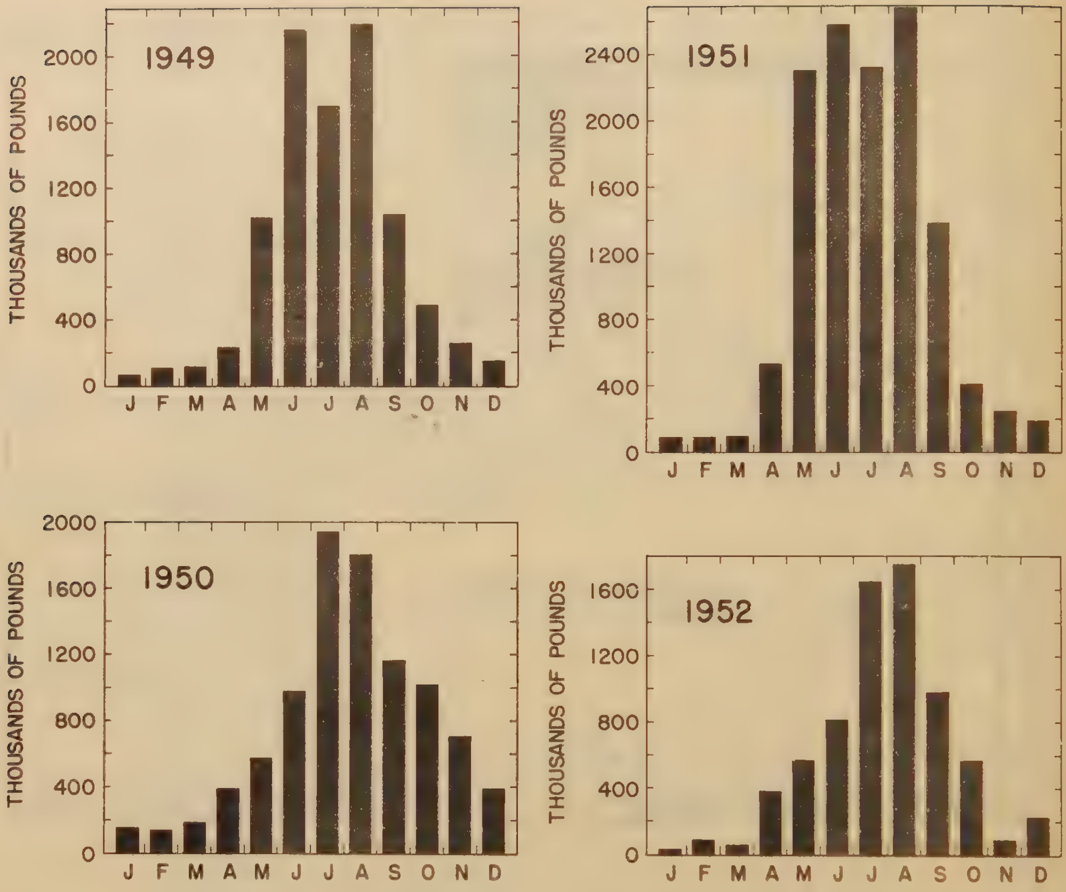


Figure 25. Hawaiian Monthly Skipjack Landings 1949-1952. The limited area of fishing and scarcity of bait are not the only restrictions on the fishery. As shown in the above diagrams, the catch during the winter season is very low with the landings seldom exceeding 200,000 pounds. Also there are large yearly fluctuations. In 1951 the total landings were 12,900,000 pounds while in 1952 they fell to 7,260,000 pounds. These highs and lows of catches prevent the development and expansion of a stable fishery industry in the Hawaiian Islands.

We do not imagine that these natural fluctuations can be controlled, but are hopeful that we can determine their causes, perhaps forecast the seasonal catch with some degree of reliability and find ways to increase or supplement the landings, especially during periods when fish are scarce.

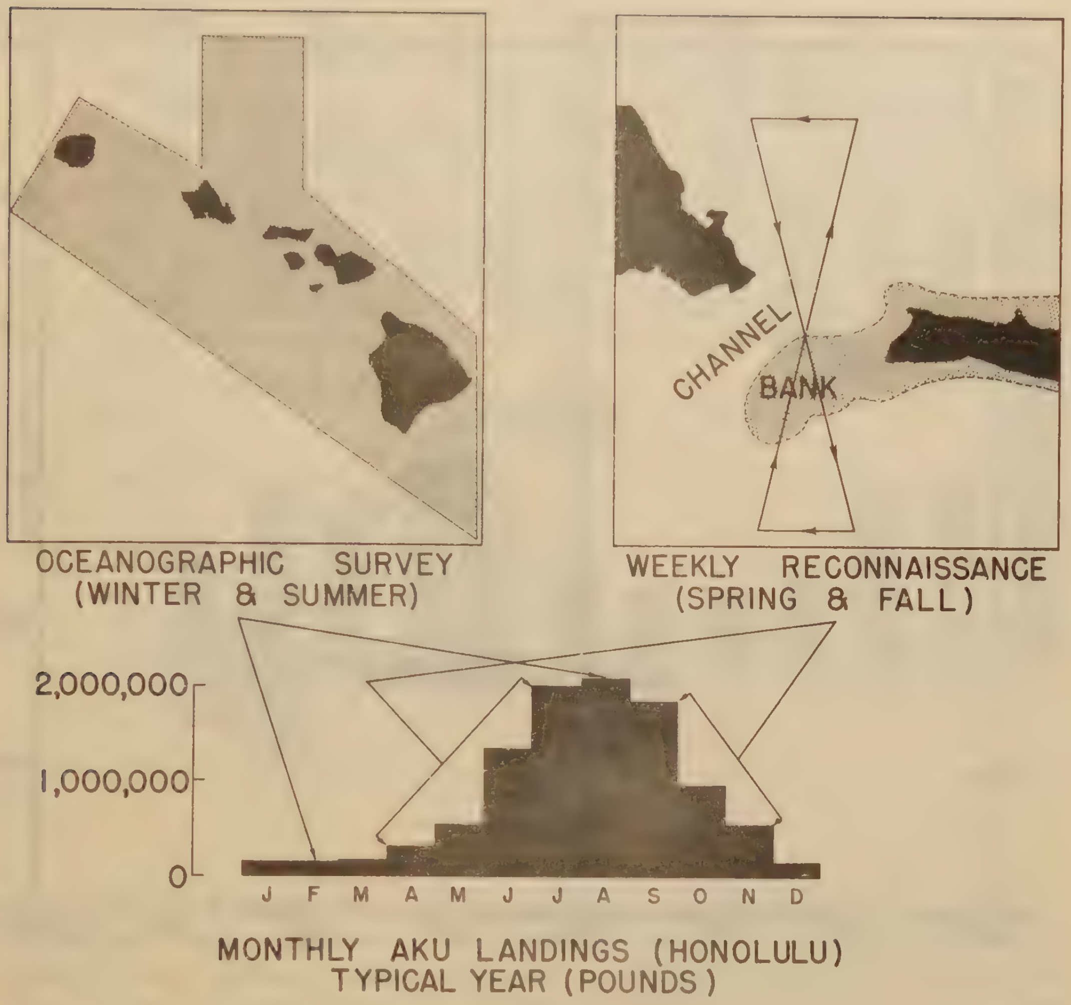

OCEANOGRAPHIC SURVEY
(WINTER & SUMMER)
CHANNEL
BANK
WEEKLY RECONNAISSANCE
(SPRING & FALL)
2,000,000
1,000,000
0
J F M A M J J A S O N D
MONTHLY AKU LANDINGS (HONOLULU)
TYPICAL YEAR (POUNDS)

Figure 26. Survey Plan for Hawaiian Hydrography. As is true for equatorial tuna, we believe that the abundance and movements of the skipjack are controlled by events in the sea. Using the skipjack catch as a guide, hydrographic surveys have been planned and are in progress to discover the events during both the changes of the seasons and at the times of greatest and least abundance. It is hoped that these surveys of both a detailed and a reconnaissance nature will yield information which will help us understand the abundance, distribution, and movements of skipjack around the Hawaiian Islands.

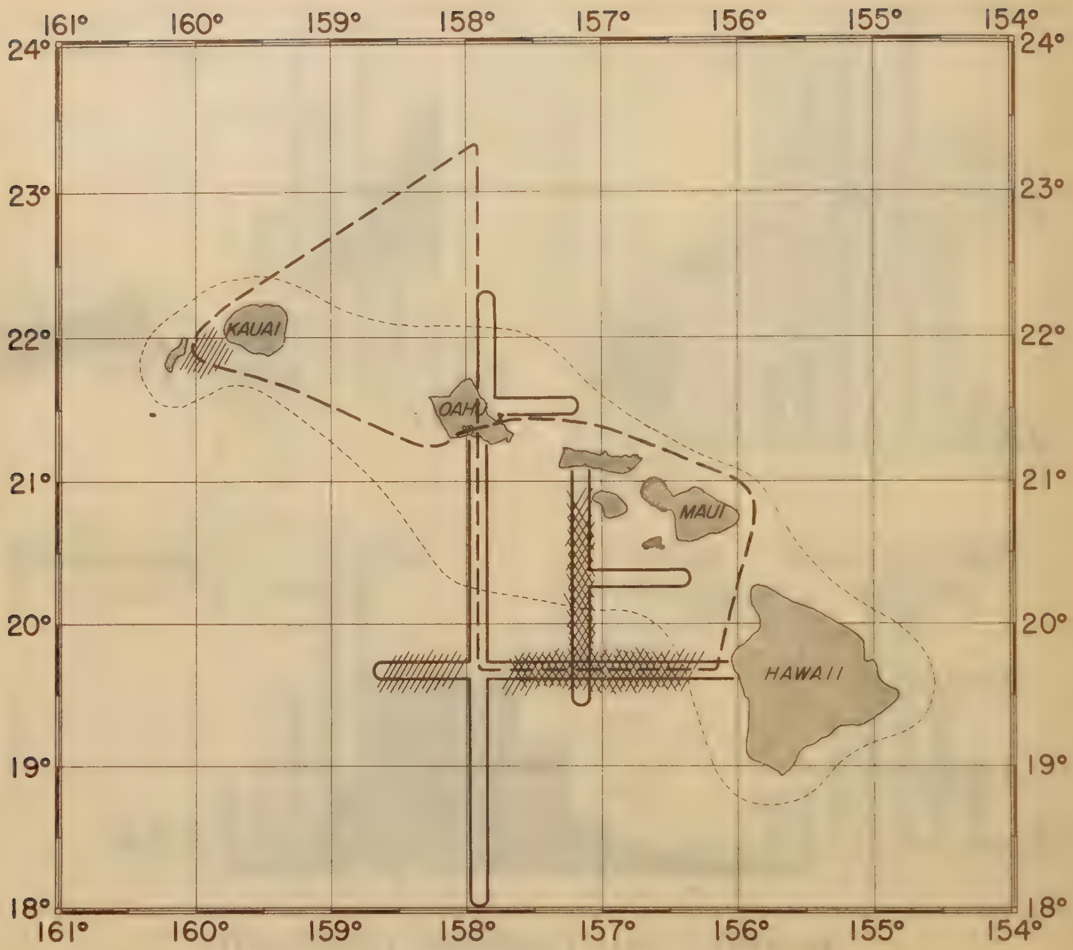


Figure 27. Winter Sightings of Skipjack. Biological studies on the skipjack and on the principal bait fishes are being carried out in cooperation with the Territorial Division of Fish and Game. POFI has undertaken as its principal contribution the study of skipjack at sea--primarily how and where to find them. As presently envisioned, this involves, in part, systematic scouting for skipjack by plane and vessel. Scouting carried on during the winter of 1951-52 and its relation to the area of local commercial fishing is summarized in the figure shown above. The heavy lines indicate some of the vessel tracks and the heavy broken lines the plane tracks; the light dashed line outlines the Hawaiian fishery. The hatched areas designate the schools of skipjack seen during the cruises. Many were seen southwest of the islands and far beyond the range of the present fishery.

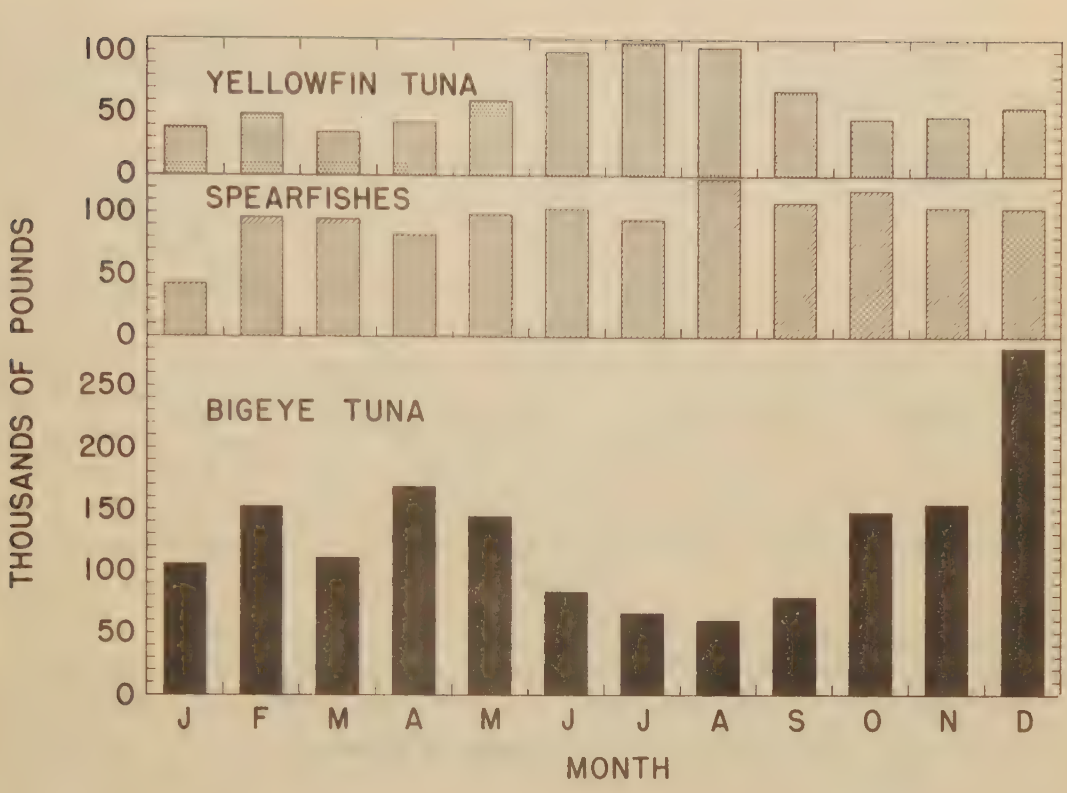


Figure 28. The Hawaiian Longline Fishery. The Hawaiian tuna longline or "flagline" fishery is second to the skipjack. This fishery lands about 4 million pounds of yellowfin and bigeye tuna and marlin each year. The three panels of the above figure show the average monthly landings for the three species for the years 1948 to 1952. Yellowfin are more plentiful during the summer while bigeye are abundant during the winter months. The catch of marlin does not seem to fluctuate much during the year. We do not know whether or not the variations in catch of these deep-swimming fish in the vicinity of the Hawaiian Islands are linked with the variations in the more abundant stock of tuna near the Equator.

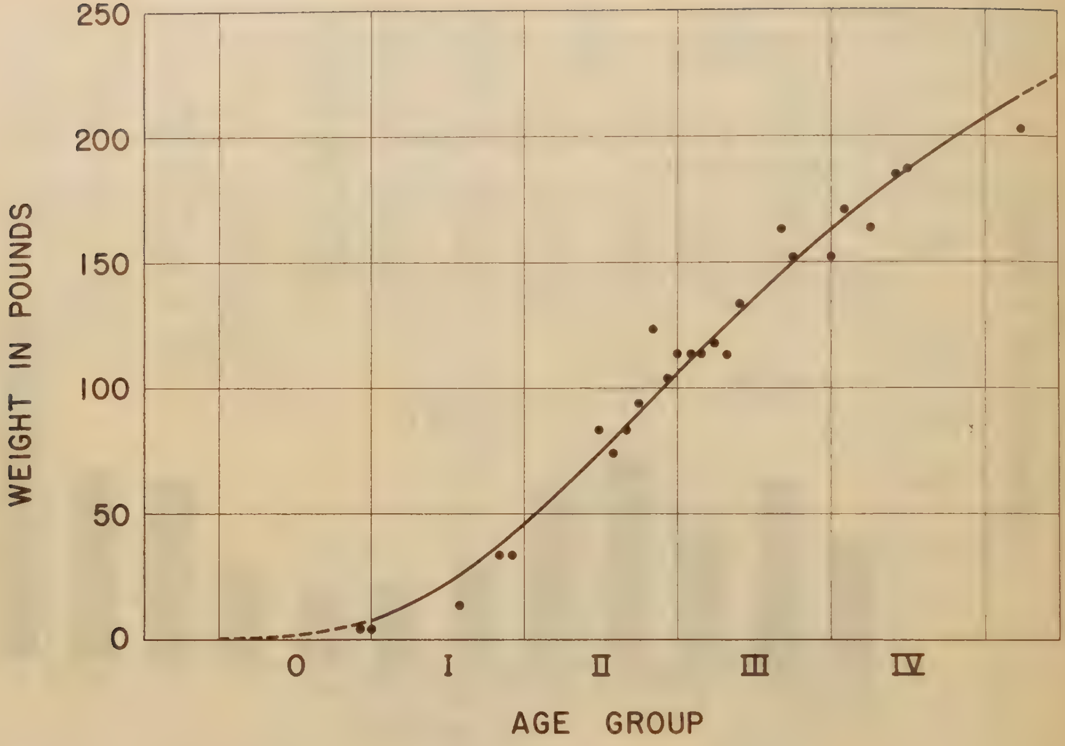


Figure 29. The Growth of Yellowfin. The local Hawaiian longline fishery affords information on the growth of the yellowfin caught near the Islands. The fish are brought into the market and weighed individually. From the records kindly made available by the marketmen, we have been able to follow size-groups in weight-frequency diagrams as they advance with growth through the months. The above curve represents the estimate by this method of the rate of growth in successive years of life. The tuna grow very rapidly during the early years of life, increasing more than 50 pounds a year in middle life. This is a very rapid growth rate but is consistent with knowledge of tuna growth obtained in other parts of the world. We expect this knowledge to help in the understanding of the peculiarities in prevalent sizes that we are finding in different parts of the Pacific.

Fishing Methods. During the early phases of our investigations we tested practically all conventional methods of fishing for tuna.

Trolling has been regularly done by POFI research vessels when underway to and from the Equator and on daylight runs between stations on hydrographic and fishing trips. During 5,525 line-hours of such incidental trolling only 15 tuna were caught; 8 were yellowfin and 7 were skipjack. In contrast, deliberate trolling close to island reefs when the vessel is maneuvered through schools at reduced speed has produced a much larger catch. In the Line and Phoenix islands we have deliberately trolled for tuna a total of 969 line-hours catching 280 tuna or 29.0 per 100 line-hours. These were practically all yellowfin tuna and most were of sizes between 16 and 60 pounds. Assuming a commercial vessel were fishing six lines, this would mean a catch of about 17 tuna or about 600 pounds per 10-hour day.

Purse seining was tried in the Phoenix Islands on two occasions, one during the summer of 1950 and the second trial during January and February 1951. During both of these attempts a number of tuna schools were sighted but rough seas and strong winds hampered the operations and no tuna were caught. Five trips were made to the Line Islands during 1950-1951. Although 75 schools of tuna were observed, most of them were too wild or too close to the reefs for setting the seine. Of the eight schools that it was possible to set on, fish were still in the circle of net when pursing began in six instances but they sounded out before the net was closed. On the other two sets the fish probably escaped before pursing began. Further purse seine trials were attempted around the Hawaiian Islands during 1951. Several schools or parts of schools were captured by engaging a sampan to chum the fish while the purse seine was set around the school. Without such chumming the fish escaped from all sets that were tried. It appears that in the central Pacific purse seining is not a practical means of capturing tuna in commercial quantities.

Surface gill nets were used in the vicinity of the Hawaiian Islands for a total of 284 hours during the summer of 1951. A report has been published on the results of these trials, most of which were carried on during the night. Fishing was confined to the lee of the larger islands because of the difficulty in handling the gear in rough waters. Some of the trials were in areas known to be productive of skipjack and during their season of abundance. A total of 28 fish were taken by the gill nets of which only 7 were tuna. It was concluded that surface gill netting also shows very little promise as a commercial fishing method for skipjack in central Pacific waters.

Fishing by the live-bait method has been attempted in the Hawaiian Islands, Phoenix, and Line Islands area by our vessels HUGH M. SMITH, HENRY O'MALLEY, and by the private vessels PIONEER, OREGON, and CALISTAR. These trials covered practically all months of the year and yellowfin and skipjack tuna were taken by all of them, mostly on the leeward sides of the islands within 3 miles of the reefs around the shore. The catch per hour's scouting was superior to that obtained by the commercial fishery around the Hawaiian Islands. The catch was predominantly yellowfin tuna in the Line and Phoenix islands while around the Hawaiian Islands the catch was predominantly skipjack.

The major limitation on the live-bait fishing method for expanding the harvest of tuna in the central Pacific either by the large tuna clippers or by the small sampans is the scarcity of suitable live-bait throughout the area. The best baiting grounds are in the main Hawaiian Islands, where a commercial fleet of sampans is now utilizing the bait stocks to the maximum. The Phoenix and Line islands show the most promise with regard to the number of surface schools of tuna found, but have little bait with which to capture tuna using the live-bait method.

Although the scarcity of live bait is the major difficulty, the large tuna clippers have additional troubles in the central Pacific. The tuna schools themselves are small, fast, and quite difficult to chum. The large clipper is less successful with these schools than the much smaller sampan type of vessel used in the live-bait fishery around the Hawaiian Islands, which has the speed and maneuverability to cope with these "wild" schools. However, the sampan is handicapped by its small carrying capacity and limited cruising range.

Longlining stands out as a method with great promise for large-scale tuna production in the central Pacific. The area of good catching rate with this gear is enormous (see fig. 20). With this gear there is no need to scout for surface schools or other fish "signs". The gear is set "blind" and does not fail to catch tuna when in the proper zone, although the catching rate varies. Weather never prevents operation and bait is no problem. Frozen herring, sardine, squid, and mackerel are all suitable for bait and available from Mainland sources. Although the tuna caught by this method are near the upper size range for canning acceptability and some are beyond it, the percentage of over-sized can be reduced to almost negligible proportions by selection of fishing grounds (see fig. 19); and eventually it should be possible to find alternative markets for the few large yellowfin as well as the incidental catch of a few bigeye tuna and spearfishes. The only serious defect of this method of fishing is the large amount of hand labor involved in setting enough of this gear to make a commercially profitable catch in the American economy. Preliminary experiments warrant confidence that a few simple modifications in the design of this gear will adapt it to mechanized hauling without seriously impairing the catching rate. This should overcome the only serious deterrent to the development of a large central Pacific fishery for tuna.

APPENDIX 1 - DATA UNDERLYING THIS REPORT

To serve the technical reader, we give for each figure and its accompanying explanatory text the kind and amount of information from which it was prepared.

Figure 1. Equatorial hydrographic cruises. Along the solid-line portions of the tracks charted in this figure, the following standard plan and procedures apply:

1. Station interval was 60 nautical miles between 15° N. and 8° S., 120 miles at higher latitudes.

2. Serial oceanographic observations were made to 1,500 meters depth during cruises 2 and 5; to 1,200 meters during cruises 8, 11, and 14; to 500 meters during cruises 15 and 19; and to 400 meters during cruise 16.

3. The properties measured were temperature, salinity, oxygen, and phosphate. Oxygen determinations were omitted subsequent to cruise 11.

4. Subsequent to cruise 2, an oblique zooplankton tow from the surface to 200 meters was taken at each station with a meter net of # 30xxx grit gauze.

5. Two 900-foot bathythermographs were taken at each station and at 10-mile intervals running along station lines. Casts were taken at 20- or 30-mile intervals while running other than along hydrographic station lines.

6. Surface current measurements were taken with the geomagnetic electrokinetograph (GEK) on cruises 14 and 19, and surface and deep currents were studied with the use of drags on cruise 16.

TABLE 1. TIME, LOCATION, AND OBSERVATIONS FROM OCEANOGRAPHIC CRUISES OF THE HUGH M. SMITH.

Cruise number	Dates	Location		Hydro-graphic stations	Plank-ton tows	BT casts
2	1/16/50-3/2/50	172°W[1]	24°N to 5°S	26	26[2]	269[4]
		158°W	5°S to 21°N	24	24[3]	215[5]
		Elsewhere		--	--	86
5	6/16/50-8/6/50	172°W[6]	27°N to 5°S	27[7]	27	208
		158°W	5°S to 21°N	24[7]	24	159
		Elsewhere		--	--	135
8	1/14/51-3/14/51	158°W	21°N to 7°S	24	24	96
		172°W[8]	14°S to 21°N	30	30	135
		155°W	2°N to 7°N[9])	50	50	280
		170°W	7°N to 7°S[9])			
		Elsewhere		--	--	23
11	8/20/51-10/6/51	150°W	5°S to 19°N	23	22	204
14	1/23/52-3/13/52	155°W	8°N to 7°S	16	16	127
		169°W	5°S to 7°N[10]	13	13	83
		180°W	9°N to 8°S[10]	18	18	119
		Elsewhere		--	--	126
15	~~3~~5/21/52-7/1/52	140°W	9°N to 7°S[11]	60	77[12]	437
16	7/23/52-8/29/52	150°W	12°N to 7°S	30[13]	30[14]	303
19	1/8/53-2/12/53	162°W	6°N	25	20	112
TOTAL				390	401	3117

Footnotes for Table 1.

1/ At northern end of leg #1, the stations were on a line from 24°N, 167°W to 14°N, 172°W.

2/ Surface and oblique tows with a meter net of # 30xxx grit gauze.

3/ Surface and oblique tows with a meter net of #18xxx grit gauze.

4/ Includes 61 casts for internal wave study made while hove-to for 24 hours at 7°00'N, 172°00'W.

5/ This includes 24 casts for internal wave study made while hove-to for 24 hours at 2°03'N, 158°08'W.

6/ At the northern end the stations were on a line from 27°N, 175°W to 21°N, 172°W.

7/ At a few stations, the serial observations extended to 3,000 and 4,000 meters.

8/ At the northern end the stations were on a line from 21°N, 167°W to 14°N, 172°W.

9/ These stations were occupied along a zig-zag course. On 7 of the 8 legs, the serial oceanographic observations were made at 6 levels down to 300 meters, and only one BT cast was made at each station.

10/ North of 5°S, serial observations extended to 600 meters.

11/ The stations were occupied 4 times during a period of 3 weeks.

12/ Includes 17 surface phytoplankton hauls made with a 1-foot diameter net.

13/ The stations were 30 nautical miles apart between 5°N and 5°S.

14/ In addition, 30 surface phytoplankton hauls were made with a Clarke-Bumpus sampler, net of 56xxx grit gauze.

Figure 2. 1953 concept of equatorial circulation. By the broad arrows shown on the surface we indicate the long known South Equatorial Current on the left, the North Equatorial Current on the right, and the Equatorial Countercurrent between them. The small arrows indicating the transverse movement are based on isenstropic concepts applied during this past year (Townsend Cromwell, in press). The easterly flowing sub-surface current underlying the Equator was discovered by use of a drift drag technique during SMITH cruise 16 (Townsend Cromwell, R. B. Montgomery, and E. D. Stroup, in press). By this technique there was also confirmed the northerly transverse movement near the surface between the Equator and countercurrent and the complete lack of transverse movement in the countercurrent itself.

Figure 3. Surface temperature and phosphate. The data for this diagram were drawn from SMITH cruise 8 and consist of thermograph records of surface temperature and inorganic phosphate determinations of water samples from 10-meter levels. The data are lacking for the middle lower portion of this figure and the course of the isopleths as drawn may differ somewhat from the exact conditions existing at the time of survey. Owing to suspected deterioration of one of the reagents used in the chemical analysis there is some doubt as to the absolute values of phosphate concentrations. We believe the error, if it exists, is consistent throughout the determinations giving consistent relative values and hence a reliable pattern of isopleths.

Figure 4. Zooplankton abundance by latitude. As an indicator of relative productivity we have used the volume of zooplankton taken in hauls of a standard type described by King and Demond (1953), which sample the larger members of the zooplankton community in the upper 200-meter stratum of water. Daytime hauls caught less, on the average, than nighttime hauls. The volumes were adjusted for this variability by a method to be described by King and Hida (ms. in preparation). Thus the volumes represent the standing crop rather than the production, but owing to uniformity of the zooplankton composition and of the temperature in the waters with which we are concerned, the rate of turnover probably is fairly uniform and the standing crop proportional to the production. The summary of zooplankton abundance in the upper panel includes all of the hauls of HUGH M. SMITH cruises

Nos. 10, 12, and 17 in waters around Hawaii (See table 7). Those of the lower panel are distributed with respect to longitude and calendar quarters as shown in table 2.

Figure 5. Zooplankton abundance by longitude and season. In this figure there has been included only the hauls taken between latitudes 10° N. and 5°S. The distribution of hauls according to the range of latitude and month of each set of hauls is given in table 3.

Figure 6. Food of yellowfin tuna. The segments of the circles are proportional to the percentage of the total volume of stomach contents comprised by each of the designated constituents. The right hand circle is based on measurement of stomach contents of 775 yellowfin tuna caught by surface trolling and surface live-bait pole and line fishing within about 5 miles of islands in the Line Islands and Phoenix Islands groups: the middle circle on 97 deep-swimming yellowfin tuna caught by longline within about 10 miles of the same islands, and the left-hand circle on 214 caught in the equatorial region more than 10 miles from islands. Detailed data appear in J. W. Reintjes and J. E. King, 1953

Figure 7. Equatorial longline fishing cruises. There is summarized in table 4 the longline fishing at the stations charted in figure 7. For the most part, the fishing at each station consisted of the setting and hauling of 40 baskets of gear aggregating 8.4 nautical miles of mainline carrying 240 hooks. The only exceptions were the HUGH M. SMITH cruise when 25 to 35 baskets were set and the CAVALIERI cruise when 50 to 85 baskets were fished at each station. Except for SMITH cruise 7 the gear was constructed according to a standard plan (Niska, 1953). In addition to fishing, bathythermograph casts (BT) and plankton hauls were made as shown in the table 4.

Figure 8. Yellowfin tuna catch/100 hooks (July-November). This chart of yellowfin tuna concentration is based on HUGH M. SMITH cruises 7, 11, 18, JOHN R. MANNING cruises 12, 13, and the CAVALIERI cruise (see table 4). Where stations located within 50 miles of each other gave varying results on successive visits, the values were averaged to determine the position of the contour lines.

TABLE [illegible] - DISTRIBUTION OF ZOOPLANKTON HAULS BY LATITUDE, LONGITUDE, AND CALENDAR QUARTER

Latitude interval	Number of hauls, by longitude intervals							
	175°01'E-175°00'W	174°59'W-165°00'W	164°59'W-155°00'W	154°59'W-145°00'W	144°59'W-135°00'W	135°59'W-125°00'W	124°59'W-115°00'W	Total
20°00' - 24°59'N:								
Jan. Feb. Mar.		3	1					4
Apr. May, June		1	1					2
July, Aug. Sept.		2	1					3
Oct. Nov. Dec.			1					1
15°00' - 19°59'N:								
Jan. Feb. Mar.		3	2					5
Apr. May, June		2	1					3
July, Aug. Sept.		3	2	3				8
Oct. Nov. Dec.			5					5
10°00' - 14°59'N:								
Jan. Feb. Mar.		8	8					16
Apr. May, June		1	2					3
July, Aug. Sept.		4	6	8				18
Oct. Nov. Dec.			5					5
5°00' - 9°59'N:								
Jan. Feb. Mar.	5	10	15	4				34
Apr. May, June		2	2		18			22
July, Aug. Sept.		6	5	9				20
Oct. Nov. Dec.		1	9			3	2	15
0°00' - 4°59'N:[1]								
Jan. Feb. Mar.	5	19	19	3				46
Apr. May, June		1	3		17			21
July, Aug. Sept.		4	9	25				38
Oct. Nov. Dec.			3			4	6	13
0°00' - 4°59'S:[1]								
Jan. Feb. Mar.	4	17	12	1				34
Apr. May,June		6	2		19			27
July, Aug. Sept.		5	6	14				25
Oct. Nov. Dec.						3	3	6
5°00' - 9°59'S:								
Jan. Feb. Mar.	4	7	5					16
Apr. May, June					6			6
July, Aug. Sept.		1						1
Oct. Nov. Dec.							2	2
Total	18	106	125	67	60	10	13	399

TABLE 3. DISTRIBUTION OF ZOOPLANKTON HAULS INCLUDED IN FIGURE 5 ACCORDING TO MONTH AND LATITUDE.

Longitude	Latitude range	Number of hauls
175°01'E - 175°00'W:		
February 1952	10°N - 5°S	14
174°59'W - 165°00'W:		
January, February 1950	9°N - 5°S	7
February 1951	7°N - 5°S	12
March 1951	10°N - 5°S	14
March 1952	7°N - 5°S	13
May, June 1951	9°N - 5°S	9
July 1950	10°N - 5°S	15
November 1950	6°N	1
Total		71
164°59'W - 155°00'W:		
January, February 1951	7°N - 0°	17
January, February 1951	10°N - 5°S	14
January, February 1952	2°N - 5°S	7
February 1950	9°N - 5°S	8
May, June 1951	8°N - 2°S	7
July, August 1950	10°N - 5°S	15
September 1951	3°N - 0°S	5
October, November 1950	10°N - 1°N	12
Total		85
154°59'W - 145°00'W:		
January 1951	6°N	1
January 1952	8°N - 4°S	7
August 1952	3°N - 4°S	14
August, September 1951	10°N - 5°S	34
Total		56
144°59'W - 135°00'W:		
May, June 1952	10°N - 5°S	54
134°59'W - 125°00'W:		
November 1952	10°N - 5°S	10
124°59'W - 115°00'W:		
October 1952	8°N - 5°S	11
Grand Total		301

TABLE 4. SUMMARY OF SURVEY LONGLINE FISHING

Cruises and dates	Latitude	Longitude	Days fishing	BT casts	Zoo-plankton hauls
HUGH M. SMITH 7:					
10/20/50-11/1/50	12°N-3°N	157°W-158°W	11	106	12
11/6/50-11/16/50	6°N-4°N	159°W-168°W	7	89	5
11/18/50-11/27/50	11°N-0°	158°W-160°W	9	100	
Elsewhere				68	7
HUGH M. SMITH 11:					
8/24/51-9/4/51	15°N-2°N	150°W	12	109	11
9/5/51-9/19/51	2°N	151°W-157°W	10	10	10
9/20/51-9/25/51	1°N-4°S	150°W	6	69	7
Elsewhere				178	
JOHN R. MANNING 11:					
1/29/52-2/6/52	8°N-2°S	155°W	9	45	
2/16/52-2/24/52	3°N-8°S	180°W	9	44	
3/4/52-3/12/52	4°N-7°S	170°W	9	59	
CHARLES H. GILBERT 1:					
5/28/52-6/4/52	9°N-1°S	119°W-120°W	8	64	
6/8/52-6/13/52	8°N-0°	129°W-130°W	6	62	
Elsewhere				53	
JOHN R. MANNING 12:					
8/14/52-8/22/52	8°N-3°S	149°W-150°W	11	54	
8/31/52-9/4/52	0° -6°S	140°W	5	18	
Elsewhere				29	
CAVALIERI:					
8/21/52-9/6/52	7°N-1°N	140°W-141°W	17	19	
9/7/52-9/12/52	2°N-3°N	142°W-149°W	6	6	
9/13/52-9/20/52	4°N-1°N	149°W-152°W	8	8	
HUGH M. SMITH 18:					
10/18/52-11/2/52	9°N-10°S	120°W-121°W	15	116	13
11/5/52-11/15/52	9°N-5°S	130°W-132°W	11	52	10
Elsewhere				17	
JOHN R. MANNING 13:					
10/17/52-10/23/52	21°N-10°N	154°W-158°W	4	20	
10/25/52-11/7/52	7°N-3°S	151°W-152°W	11	68	
11/19/52-11/28/52	4°N-5°S	168°W-170°W	10	50	
Total			~~195~~ 194	1513	75

Figure 9. Yellowfin tuna catch/100 hooks (January-June). This chart is based on JOHN R. MANNING cruise 11 and CHARLES H. GILBERT cruise 1 (see table 4).

Figure 10. Relative abundance of yellowfin tuna in the western equatorial Pacific. Catches of the nine Japanese mothership tuna fishing expeditions from June 1950 to October 1951 were summarized by catching area. The weighted mean number of yellowfin caught per hundred hooks fished was computed for each rectangle of 1° of latitude by 5° of longitude as the basis for drawing the contour lines of figure 11.

Figure 11. Seasonal fluctuations in the longline catch rate in the western Pacific. Each bar represents the weighted mean number of yellowfin tuna caught per hundred hooks fished between latitude 1°N. and 5°N. by all boats of the nine Japanese mothership tuna fishing expeditions from June 1950 to October 1951.

Figure 12. Comparison of catch rates from Japanese commercial and POFI experimental fishing. There are included in this graph the results of Japanese commercial fishing for 21 days at the several latitudes along longitude 170°W. during the period October 27 to November 23, 1952, and the results of 10 days' fishing by the JOHN R. MANNING along the same longitude during the period November 19-28, 1952. The Japanese fished with 390 baskets per day, on the average, whereas the MANNING set only 40 baskets per day.

Figure 13. Abundance of yellowfin at 150° W. longitude on successive cruises. This graph is based on HUGH M. SMITH cruise 11, JOHN R. MANNING cruises 11, 12, 13, and the CAVALIERI cruise. The catches are the average of the four adjacent stations with the highest catch rate along the given longitude. Thus they represent the richest 240-mile-wide band regardless of the latitudinal shifts in this band.

Figure 14. Tuna spawning near the Equator. The determinations were made by Fred C. June by measuring the diameter of ova in the gonad and classifying the degree of maturity according to criteria given in Fred C. June, 1953.

Figure 15. Distribution of tuna larvae in central Pacific. The values given in the graph are based on the plankton tows taken on HUGH M. SMITH cruises 5, 8, and 11. When tuna larvae are less than 5 millimeters (one-fifth of an inch), we have not been able to identify them as to species. However, we find it possible to identify larvae of yellowfin after they have reached more than 5 millimeters of length. It is likely that many of the larvae designated as "all other tuna larvae" are also yellowfin tuna.

Figure 16. Index to racial difference of yellowfin between sample localities. In table 5 are listed the numbers of yellowfin tuna whose morphometric measurements entered the calculations on which figure 17 is based. The numerical values given in this figure are the "reduced coefficient of racial likeness" computed according to the formula:

$$R\ C\ R\ L = 50\left(\frac{\bar{n}_1 + \bar{n}_2}{\bar{n}_1 \bar{n}_2}\right)\left[\Sigma\left\{\frac{1}{M}\left(\frac{(m_s - m_{s'})^2}{\frac{\sigma_s^2}{n_s} + \frac{\sigma_{s'}^2}{n_{s'}}}\right)\right\} - 1\right]$$

in which m_s is the mean of the sth character estimated for 100 cm. fork length, σ_s the standard error of estimate of the regression of the sth character on fork length, n_s the number of observations of the sth character, $\bar{n}$, the mean number of observations of all characters in the sample and M the number of characters. The symbols s' and n_2 refer to the characters in the second sample.

Figure 17. Equatorial commercial fishing. Because of the especial interest attached to the commercial aspects of equatorial fishing results there is given herewith in table 6 the results of each day's fishing by the CAVALIERI. Of the fish included in this table, 17.7% of the yellowfin, 16.9% of the bigeye and 10.3% of the skipjack were damaged by sharks. It is estimated that the damage on approximately half of these was slight enough not to have affected their commercial acceptability. The yellowfin taken east of 145° W. longitude averaged 148 lbs. each while those taken west of this meridian averaged only 128 lbs.

TABLE 5. NUMBER OF YELLOWFIN TUNA FOR WHICH MORPHOMETRICAL MEASUREMENTS WERE TAKEN BY LOCALITY AND LENGTH CLASSES

Locality	Length cm													
	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-99.9	100-109.9	110-119.9	120-129.9	130-139.9	140-149.9	150-159.9	160-179.9	Total
North of 10°N lat:														
Hawaii	16	15	3	2	4	9	15	6	17	29	22	15	50	203
Japan	12	6	6	8	8	6	1							47
Off Luzon, P. I. 1/	1	59	122	62	47	19	9	6	15	11	5	2		358
10°N to 10°S lat:														
Costa Rica		2	7	3	6	11	6	6	2		2	1		46
120° -130°W						1			3	5	17	13	4	43
Line I.	1	2	9	25	30	31	31	21	17	19	24	39	6	255
Palmyra 2/		1	10	24	18	27	10	2	1		1			94
Phoenix I.		4	18	14	16	19	10	24	13	8	3		1	130
Marshall I. 3/		21	6	4	5	4	3	1						44
Caroline I.														
Eastern	1	8	23	18	19	16	6	14	12	21	9	11	1	159
Central	1	6	11	19	21	21	33	27	33	24	13	2		211
Western			2	1	1	3		2	7	1				17
South of 10°S lat:														
Society	2	15	3	2	8	1					2			33
Fiji 2/		1	2		3	1	6							13
Total	34	140	222	182	186	169	130	109	120	118	98	83	62	1653

1/ Measurements supplied by Dr. D. V. Villadolid.

2/ Godsil and Greenhood (1951).

3/ Measurements supplied by Mr. J. C. Marr, Fish and Wildlife Service, Stanford, California. Partly collected near Bikini Atoll, which is at 12°N latitude.

TABLE 6. CATCH RECORD OF THE SEMI-COMMERCIAL FISHING OF THE CAVALIERI, AUGUST 21 TO SEPTEMBER 20, 1952.

Date	Position		Baskets	Yellowfin	Bigeye	Skipjack	Marlin	Shark
	Latitude	Longitude						
Aug. 21	07°07'N	140°47.6'W	50	2	1		2	2
22	05°58'	140°30'	50	4	1		2	11
23	05°14'	140°14'	60	15	4			8
24	04°23'	139°38'	60	18		4		3
25	03°26'	139°56'	60	34	7	2		8
26	02°23'	140°02.5	61	32				5
27	01°32'	139°55'	70	49		1		12
28	00°59'	140°07'	70	12		1	1	6
29	02°05'	140°22'	70	24		1		6
30	03°37'	140°15'	70	25	1	1	1	7
31	03°39'	140°15'	76	34			1	12
Sept. 1	03°31'	140°12.5'	70	13		1		6
2	03°04.5'	139°52'	79	19		4		5
3	04°02'	139°57'	79	8				14
4	03°15.5'	139°58'	60	12	1			3
5	02°24'	140°12'	75	22	4	2		
6	02°11'	140°32'	79	23	3	1		6
7	01°51'	141°49.5'	80	18	3		1	6
8	02°25'	142°04'	80	23	4			5
9	02°30.5'	142°57'	80	21	1			7
10	02°12'	144°59'	80	15	1	5		2
11	02°45'	147°05.5'	80	20			1	5
12	02°25'	148°47'	80	9	4		1	10
13	01°17'	149°18'	80	27	4	1	2	8
14	01°34'	149°47.5'	81	27	2	2		9
15	01°57.5'	150°02'	80	24	2		2	3
16	02°23.5'	150°17'	85	15	2		2	1
17	03°19'	151°24'	80	33	3		1	1
18	03°37'	151°36'	80	61	6	3	1	8
19	03°44.5'	151°54.5'	80	43	6			4
20	04°04'	152°10.5'	80	38	5			12
Total				720	65	29	18	195

Note: Of the above the following were damaged by sharks: yellowfin, 17.7%; bigeye, 16.9%, skipjack, 10.3%.

Figure 18. Acceptance of CAVALIERI longline tuna for canning. The percentages indicated in the graph are based on a sample of the catch which was tagged prior to unloading. In this manner individual fish could be identified with their original weights after the precooking operation, which is the stage when the acceptability of fish is established. The sample consisted of 72 out of a total catch of 720 yellowfin.

Figure 19. Variation in size of yellowfin along the Equator. The data plotted in this figure were taken from length measurements converted to weights according to a weight on length regression. Included are lengths of 10,048 yellowfin tuna from equatorial survey catches distributed as follows:

Japanese mothership expeditions:		POFI survey fishing:	
138°E.	195	180°W.	55
145°E.	2,699	170°W.	107
151°E.	382	160°W.	137
158°E.	3,254	155°W.	75
165°E.	1,236	150°W.	722
172°E.	730	145°W.	98
		140°W.	308
		130°W.	31
		120°W.	19

Figure 20. Known trans-Pacific distribution of yellowfin tuna. The geographical extent of the Japanese longline fishery is based on published records of pre-war Japanese fishing activities, on data from POFI observers' records on Japanese mothership expeditions from occupied Japan, and on gleanings from newspaper and trade journal accounts of post-treaty Japanese fishing. The outline indicating the area of American yellowfin and skipjack fishery follows Godsil (1938 Calif. F.B. 51, figure 3).

Figure 21. Bait resources in the central Pacific. Material of this figure and the text below it were drawn from June and Reintjes, 1953.

Figure 22. Mid-winter sampan fishing in Line Islands. The sampan TRADEWIND with a crew of 10 men sailed from

Honolulu January 8, 1953 and returned February 12, 1953. Some pertinent data are:

Running	13 days
Fishing for bait	7 days
Fishing for tuna	8 days
Fishing for market fish	4 days
Transferring fish and supplies	2 days
Weatherbound	2 days
Total	26 days

Fishing for bait:

Palmyra I., 20 hauls caught 2,315 lbs. mullet.
Christmas I., 5 hauls caught 840 lbs. mixed fish.
Fanning I., 6 hauls caught 850 lbs. mullet.

Fishing for tuna:

Palmyra I., 16 schools worked, 7 tons caught.
Christmas I., 1 school worked, none caught.
Fanning I., 10 schools worked, 6-1/2 tons caught.
Incidental trolling, 71 tuna caught.

Proceeds from sale of fish	$3,809
Expenses	$2,426
Share per fisherman	$ 164

Figure 23. Search for bait substitutes. This figure summarizes experiments conducted during 1952 by contract with the University of Hawaii under the direction of Prof. Albert L. Tester at the University's Marine Laboratory on Coconut Island, Oahu. The tests of chemical fractions, shown as shaded portions of the bars, were directed toward discovery of the chemical identity of the attractive substance in the various extracts of fish tissues.

Figure 24. Distribution of skipjack catch around the Hawaiian Islands. Each dot on the chart represents a catch of 50,000 pounds made during the average year of the years 1948 to 1952 according to statistics collected by Territory of Hawaii, Board of Commissioners of Agriculture and Forestry, Division of Fish and Game.

Figure 25. Hawaiian skipjack landings 1949-1952. The data shown on these graphs are the catches of the live-bait tuna fleet of Hawaii and were furnished by the Territory of Hawaii, Board of Commissioners of Agriculture and Forestry, Division of Fish and Game. The figures for the last 2 months of 1952 are preliminary totals subject to revision.

Figure 26. Survey plan for Hawaiian hydrography. Our plans for future work are based in part on a considerable amount of hydrographic observations and plankton tows already made in Hawaiian waters and summarized in table 7.

These observations were taken as follows:

1. The station pattern was planned to cover waters immediately around the islands and extending offshore 50-100 miles in order to include the transition from conditions associated with the presence of islands to conditions that are practically oceanic.

2. At each station serial oceanographic observations were taken to 1, 200 meters except where the water was too shoal.

3. The properties measured were temperature and salinity on all cruises and included dissolved oxygen on cruises 1 and 10 and inorganic phosphate on cruises 10, 12, 17, and 20.

4. Zooplankton hauls were of approximately 1/2-hour duration and were taken with a meter net of 30xxx grit gauze in the manner indicated. Cruise 1, being the shakedown cruise, also tested nets of 56xxx and 18xxx mesh.

5. Two bathythermograph casts were made at each station and at 10-mile intervals between stations. They were to 900 feet on all cruises with the exception of the first six casts on cruise 1, which were to 450 feet.

6. Surface current measurements on station and midway between stations were taken with the geomagnetic electrokinetograph (GEK) on cruises 12 and 20.

TABLE 7. OCEANOGRAPHIC CRUISES IN WATERS SURROUNDING THE HAWAIIAN ARCHIPELAGO.

Cruise number[1]	Dates	Stations		Zooplankton Hauls		BT casts
		Number occupied	Usual spacing[2]	Type	No. taken	
S I	12/8/49-12/21/49	16[3]	30[4]	Surface, horizontal	14	80
S 10	7/19/51-7/31/51	33	40	Oblique to 200 m.	33	169
M 8	9/23/51-10/19/51	--	--	Oblique to 200 m.	36	69
S 12	10/23/51-11/3/51	30	40	Surface, horizontal	30	147
S 17	9/5/52-9/15/52	31[5]	45	Oblique to 200 m.	30[6]	160
S 20	2/25/53-4/4/53	69	40[7]	Oblique to 200 m.[8]	69	235
Total		179			212	860

[1] Cruises made by the JOHN R. MANNING are prefixed with M, those by the HUGH M. SMITH, with S.

[2] Station spacing is in nautical miles.

[3] Serial observations were to various depths down to 1,500 meters.

[4] On lines 100 miles apart.

[5] Serial observations were to 700 meters.

[6] In addition, surface phytoplankton hauls were made at 9 stations with a 1-foot net, #25 silk.

[7] Two legs to 29° N have a station spacing of 60 miles.

[8] One surface tow on Penguin Banks, 21°-5'N, 157°36'W.

Figure 27. Winter sightings of skipjack. Charted in this figure is the track of CHARLES H. GILBERT cruise 7 and flights 2 and 3. Altogether there were four scouting cruises and four flights between September 1952 and March 1953.

Figure 28. The Hawaiian longline fishery. Statistics were furnished by the Territory of Hawaii, Board of Commissioners of Agriculture and Forestry, Division of Fish and Game.

Figure 29. The age and growth of yellowfin. This figure is adapted from Harvey L. Moore, 1951, figure 9.

APPENDIX 2 - PUBLICATIONS RESULTING FROM PACIFIC OCEANIC FISHERY INVESTIGATIONS

Bates, Donald H., Jr.

1950. Tuna trolling in the Line Islands in the late spring of 1950. U. S. Fish and Wildlife Service Fishery Leaflet 351, Oct. 1950.

Cleaver, Fred C. and Bell M. Shimada.

1950. Japanese fishing methods for skipjack (*Katsuwonus pelamis*). U. S. Fish and Wildlife Service Comm. Fish. Rev., Vol. 12, No. 11, Nov. 1950, pp. 1-27. Sep. No. 260.

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1951. Mid-Pacific oceanography, January through March 1950. U. S. Fish and Wildlife Service Spec. Sci. Report: Fish. No. 54, July 1951.

1953. Circulation in a meridional plane in the central equatorial Pacific. Jour. of Mar. Res., Vol. 12, No. 2.

--------, R. B. Montgomery and E. D. Stroup.

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4. Variations in zooplankton abundance in Hawaiian waters, 1950-1952.
5. The variability of estimates of yellowfin tuna from longline catches.
6. Occurrence of tuna in surface waters of the Central Pacific as indicated by trolling and by sighting fish schools and bird flocks.
7. Analysis of the catches of nine Japanese mother-ship expeditions to the western tropical Pacific.
8. Longline fishing for deep-swimming tunas in the central Pacific, August to November 1952.
9. The oxygen requirements of Hawaiian tuna bait fish.
10. The tuna long-line fishery of Hawaii, 1949-1952.
11. The response of tuna to chemical stimuli, 1952-1953.

APPENDIX 3 - TRANSLATIONS

The following foreign-language fisheries publications are currently received, reviewed, and significant articles are translated. (For publications which also have English titles, the title in the original language is given in parentheses; for those which do not, the translation of the original title is given in brackets.)

Arsberetning fra Danmarks fiskeri- og havsundersøgelser [Annual report of Danish fishery and sea investigations].

Berita Perikanan [Fishery News], published by the Sea Fisheries Service of the Republic of Indonesia.

Boletín and Contribuiciones Técnicas, Instituto de Pesca del Pacífico [Bulletin and Technical Contributions, Fishery Institute of the Pacific] (Mexico).

Boletin and Trabajos, Instituto Español de Oceanografía [Bulletin and Works, Spanish Institute of Oceanography].

Bollettino di Pesca, Piscicoltura e Idrobiologia [Bulletin of Fisheries, Fish-culture, and Hydrobiology] (Italy).

Bulletin of the Faculty of Fisheries, Hokkaidō University (Hokkaidō Daigaku Suisangakubu Kenkyu Ihō).

Bulletin of the Japanese Society of Scientific Fisheries (Nippon Suisan Gakkai Shi).

Bulletin of the Tōkai Regional Fisheries Research Laboratory (Tōkaiku Suisan Kenkyūsho Kenkyū Hōkoku).

Ciencias Zoológicas and Miscelanea, Museo Argentino de Ciencias Naturales Bernardino Rivadivia [Zoological Sciences and Miscellany, Bernardino Rivadivia Argentine Museum of Natural Sciences].

Die Fischwirtschaft [The Fish Business] (Germany).

España Pesquera [Fisheries Spain].

Fishing Industry Weekly (Suisan Shūhō) (Japan).

Investigaciones Zoológicas Chileñas [Chilean Zoological Investigations].

Jahresbericht über die Deutsche Fischerei [Yearly Report on the German Fisheries].

Japanese Journal of Ichthyology (Gyoruigaku Zasshi).

Journal of the Faculty of Fisheries, Mie Prefectural University (Mie Kenritsu Daigaku Suisangakubu Kiyō).

Journal of the Fukuoka Prefectural Fishery Experiment Station (Fukuoka-ken Suisan Shikenjō Hōkoku).

Journal of the Fisheries Research Institute (Suisan Kenkyūkai Hō) (Japan).

Journal of the Shimonoseki College of Fisheries (Nōrinshō Suisan Kōshūjo Kenkyū Hōkoku).

Kanagawa Suiken Geppō [Monthly Report of the Kanagawa Prefecture Fisheries Experiment Station].

Kanagawa-ken Suisan Shikenjo Gyōmu Hōkoku [Progress Reports of the Kanagawa Prefecture Fisheries Experiment Station].

Memorie, Comitato Talassografico Italiano [Memoirs of the Italian Oceanographic Committee].

Nippon Suisan KK. Kenkyūsho Hōkoku [Nippon Suisan Co. Research Laboratory Reports].

Nippon Suisan Shimbun [Japan Fisheries Newspaper].

Pesca y Caza [Fishing and Hunting] (Peru).

Protokolle zur Fischereitechnik, Institut für Netz- und Materialforschung [Reports on Fishery Technology, Institute for Net and Materials Research] (Germany).

Publicaciones del Instituto de Biología Aplicada, Barcelona [Publications of the Institute of Applied Biology, Barcelona].

Reports of the Nankai Regional Fisheries Research Laboratory (Nankai-ku Suisan Kenkyūsho Hōkoku).

Skrifter Udgivet af Kommissionen for Danmarks Fiskeri- og Havsundersøgelser [Papers Published by the Commission for Danish Fishery and Oceanographic Research].

Suisan Jihō [The Fishery Times] (Japan).

Suisankai [Journal of the Fisheries Society of Japan].

From the above journals and from other sources the following papers have been translated by Wilvan G. Van Campen and others. For those articles which have English abstracts, the titles given are the authors' original English titles rather than translations of the foreign-language titles. The majority of these translations have been published in Special Scientific Reports: Fisheries, as noted; those which have not been published are held in the POFI library and are available for interlibrary loan.

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MID-PACIFIC OCEANOGRAPHY

Part IV, Transequatorial Waters, January-March, 1952

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 135

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

MID-PACIFIC OCEANOGRAPHY, PART IV

TRANSEQUATORIAL WATERS

JANUARY-MARCH 1952

By

E. D. Stroup
Physical Science Aid
Pacific Oceanic Fishery Investigations
Honolulu, T. H.

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Introduction

This report is concerned with cruise 14 of the M/V Hugh M. Smith, the fifth in a series of equatorial oceanographic cruises by the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service.[1] The cruise was carried out in January and February 1952 in conjunction with longline tuna fishing in the same area on cruise 11 of the M/V John R. Manning; the results of the fishing have been described by Murphy and Shomura (1953). The purpose of these simultaneous operations was to help relate the occurrence of tunas to the oceanography of the upper layers in the equatorial Pacific between 155° W. and 180° longitude.

Measurements of surface and subsurface temperature, salinity, and inorganic phosphate as well as plankton collections were made during Smith cruise 14. The purpose of this report is to present the tabulated station data and various vertical sections, with minimum analysis of results. There are, in addition, brief descriptions of one of the smaller features of the area. The results of the plankton collections will appear in later reports.

Vessel, Equipment, and Procedures

The shipboard equipment was essentially as described by Cromwell (1951), except that the hydrographic winch and work platform were raised to a safer and more workable location on the boat deck, about 6 meters above the sea surface (see frontispiece). The main-deck laboratories were also redesigned for greater convenience. The methods of collection and processing of the raw data have been described in detail (Cromwell 1951, 1954).

The treatment of the observed data from Smith cruise 14 leading to their ultimate presentation as interpolated data and vertical sections differs somewhat from the previous cruises. Smith cruises 5 and 8 (Cromwell 1954) and 11 (Austin 1954) were presented using modifications of the methods proposed by Montgomery in his evaluation of a Smith cruise 2 section (Montgomery 1954). The procedures used in the analysis of Smith cruise 14 are, in effect, an extension of Montgomery's method, embodying, in addition to the methods he employed, several further details suggested in his paper. An outline of the method of analysis will be given here; reference to the reports above (especially Montgomery 1954) should be made for detailed discussion and theoretical consideration.

The basic representation of each oceanographic station was made on a graph embodying a temperature scale vs. scales of depth, salinity, and phosphate phosphorous, with lines of constant sigma-t corresponding to the temperature and salinity arguments also included on the graph (fig. 1). Temperature-depth curves for each station were first drawn, passing through the values obtained from the reversing thermometers but utilizing the shape of the station bathythermograph (BT) trace to define detail in the upper 270 meters. Temperature-salinity and temperature-phosphate curves (station "characteristic curves") were then drawn. Values from adjacent stations, and in many cases from stations two or three removed on the same longitude, assisted in construction of the curves between observed points; this was readily accomplished by superposing the station graphs on a light table during the drawing. The necessity for this procedure is evident in an examination of the vertical sections (see below). The depths sampled by the Nansen bottles (entered as dots on the sections) necessarily often miss some of the major features of the distributions, especially in the region of the thermocline, but by utilizing adjacent-station values the continuity of these features is not destroyed. The variations in these characteristic curves with latitude were made as regular as possible, and, so far as the observed data permitted, maxima and minima were located on the same respective values of sigma-t from station to station.

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[1] Certain results of the previous cruises in this series appear in reports by Cromwell (1951, 1953, 1954), Austin (1954), and Montgomery (1954).

Depths of sigma-t, salinity, and phosphate phosphorous at the desired isopleth values were taken from each station graph by referring to the common temperature scale and the temperature-depth curve, and each of these properties was plotted on a meridional section. Temperature sections to the same scales of latitude and depth were drawn for each station line of the cruise from the complete BT data (these were used in the analysis but are omitted here in favor of temperature sections with greater vertical exaggeration). The plots of sigma-t were then placed over the temperature sections on a light table and the isopleths were drawn, allowing the grosser detail of the temperature sections to influence the sigma-t sections between stations. The salinity and phosphate phosphorous plots were next drawn over the sigma-t sections in a similar fashion, with their isopleths made as nearly as possible parallel to the isopleths of sigma-t. In view of the extensive adjusting of the characteristic curves to obtain continuity between stations, the interpolated values of sigma-t, salinity, and phosphate phosphorous plotted on the sections were followed exactly during the drawing.

Values of temperature and salinity at standard depths were taken from the station graphs for use in the computation of geostrophic currents. The values of sigma-t tabulated at standard depths were computed from these temperature and salinity values, rather than read directly from the station graphs.

The most evident new procedure, that of allowing the BT temperature sections to influence construction of the sigma-t (and thus salinity and phosphate) sections, has been instituted to achieve consistency between the distributions of temperature and density, and internal consistency in the method of analysis. It is certainly not argued that all the detail thus introduced into the density distribution is meaningful from every point of view, but a more accurate presentation of the observed field of density is obtained than by merely drawing smooth curves through the station points. As a practical consideration, it is a great deal easier to include all the larger detail than to set up any arbitrary criterion for smoothing which would then have to be invoked continuously during the drawing of a section.

The method of mutual adjustment of the station characteristic curves is based on the fact that the ocean is continuous; with the present sampling methods this assistance between stations probably gives a closer representation of actuality than methods treating each station individually. The location of the maxima and minima of these curves on continuous values of sigma-t from station to station, and the subsequent drawing of the isopleths of the salinity and phosphate sections parallel to the isopleths of sigma-t, are based on the consideration that flow in the ocean normally takes place along surfaces of constant potential density, which are closely approximated by surfaces of constant sigma-t, and that mixing of by far the greatest magnitude takes place along these same surfaces.

Some Results of Hugh M. Smith Cruise 14

The station pattern for Smith cruise 14 appears in figure 2. The stations along 155° W. longitude consisted of casts to at least 1,000 meters; to permit greater definition of detail in the region of interest the other two lines of stations were mostly limited to the upper 700 meters. Figures 3 to 7, describing the section at 155° W. longitude are in the sequence: dynamic topography, geostrophic currents, temperature, sigma-t, salinity. The second series of figures (8 to 11), describing the section at 180° longitude and the third (12 to 15), describing the section at 169° W. longitude are in the sequence: temperature, sigma-t, salinity, phosphate. Figure 16 presents temperature sections on 155° W., 169° W. and 180° longitudes, taken on the fishing station lines of John R. Manning cruise 11.

The numbers and positions of the stations are indicated on each section. For each variable except temperature, the location of every observation carried in the tabulated data is indicated by a spot on the vertical section in question. When there was serious doubt regarding the accuracy of an observation, it was not used in constructing the vertical section, and a footnote to this effect was entered in the tabulated data. Observations unquestionably in error were dropped from the tabulations.

To make the relations between the different fields more readily apparent, selected isopleths of sigma-t have been plotted as dashed lines directly on the vertical sections of salinity and phosphate and on the section of computed currents. The two shallower isopleths roughly define the upper and lower boundaries of the strong density gradient in the thermocline.

Comparison of the temperature sections from *Smith* cruise 14 and *Manning* cruise 11 indicates that changes in the minor features of the various distributions may be quite rapid; this has been verified by the results of a subsequent cruise (*Smith* cruise 15, Austin MS.). For this reason no attempt has been made to plot any form of horizontal distribution over the area covered by *Smith* cruise 14.

It should be noted that the winds, atypically, were predominantly north of east over the entire area during the period of the cruise (wind data are listed for each station in the tabulated data).

Computed currents--As indicated above, only the stations along 155° W. longitude were of sufficient depth to permit computation of geostrophic currents relative to a 1,000-meter level of no motion (except for three stations on 180° longitude, see below). The smoothed dynamic topographies of selected isobaric surfaces with respect to the 1,000-decibar surface are shown in figure 3; the computed dynamic heights at each station are carried as dots. Owing to equipment malfunctions the observations at 0°54'N. latitude and 3°00'S. latitude were too shallow to permit computation relative to this surface. From these smoothed topographies the currents shown in figure 4 were computed. The computation of currents becomes highly uncertain, and is not attempted, within 3° of the Equator.

In the surface layer, the Equatorial Countercurrent is found from the northernmost station at 8° N. latitude to the southern boundary at 4° N. latitude; the *Smith* temperature section on this longitude (see below) indicates the northern boundary at approximately 9°30'N. latitude. The westerly South Equatorial Current is found south of 4° N. latitude.

The three southernmost stations of the 180° longitude line reached 1,000 meters, and computation of dynamic heights of isobaric surfaces relative to this level have been carried out; these are carried in the tabulated data but not in a figure, and no currents have been computed. Examination of the data indicates that the currents in the surface layer were variable and perhaps partly easterly.

Temperature--Temperature sections from the BT data appear in figures 5, 8, 12, and 16. As mentioned above, in order to reveal detail these sections were constructed with greater vertical exaggeration than those of the other variables. The BT casts from which the *Smith* sections were drawn were taken every 10 miles between stations, and every 30 miles along 155° W. longitude north of 8° N. latitude. Two casts were taken at each station; the one nearest in time to the hydrographic cast was plotted in each case. The *Manning* sections are drawn from casts made on the fishing stations only. The *Manning* fished one station per day; the date of the first station on each line is given in the figure caption.

On each section the downward slope of the thermocline away from the Equator to north and south (as distinguished from the pronounced arching of the shallower isotherms at the Equator) is evidence of the distribution of mass associated with the South Equatorial Current, and the northward rise starting a few degrees north of the Equator is associated with the easterly flow of the Equatorial Countercurrent. Only the *Smith* section along 155° W. longitude extends beyond this into the North Equatorial Current, indicated by a second northward deepening. The southward rise of the isotherms at the southern end of the 180° longitude line is reflected in the weakening of the westerly flow indicated here by the computed dynamic heights of isobaric surfaces. These gross "topographic" features, associated primarily with zonal currents, are reflected in the distributions of each of the variables. In the surface layer, lower temperatures at the Equator are evidence of the addition of water from somewhat greater depths.

As mentioned above, a comparison of the *Smith* and *Manning* sections indicates the possibility of quite considerable changes in detail in a relatively short time, although the basic features remain distinct.

Surface temperatures are indicated at the top of each temperature section. These are often influenced by shallow diurnal effects, as at 3°15'N. latitude, 180° longitude (fig. 8); no attempt was made to include these temporary variations in the vertical temperature sections.

Several of the details of the temperature field, such as the reduction of the vertical temperature gradient at the Equator and the presence of stable inversions in the thermocline near the Equator, are described in reports of this series (Cromwell 1954, Austin MS.). Both of these features are seen on each of the *Smith* cruise 14 temperature sections. A detail not so far described is the persistent, relatively "sharp" bottom of the main thermocline at about 2°-3° N. latitude. Figure 17 presents BT traces taken near these latitudes on various longitudes during several cruises. The traces best illustrating the phenomenon were chosen from a meridional series in each case, demonstrating a remarkable consistency in position; it has moreover never been completely absent. Figure 18 gives the detailed temperature structure on the oblique section marked on figure 2. The most evident "sharp" bottom of the thermocline is seen at 2°06'N. latitude, 175°04'W. longitude; this particular trace is second from the left in figure 17.

Sigma-t--The distribution of sigma-t is shown in figures 6, 9, and 13. These figures are closely associated with, and share most of the details of, the temperature sections (see procedures). For an exception to this rather general rule, the surface layer decrease in density at the southern end of the 180° longitude line is largely associated with a decrease in salinity. The expected slight east to west thickening of the light surface layer may be seen in a comparison of the sections.

There is a marked meridional change in the character of the water just beneath the main thermocline in approximately the 2°-3° N. latitude region discussed above; this feature is reflected in the sharp southerly increase in depth of the sigma-t isopleths 26.6 to 27.0 in this area. The effect of this distribution of density is evident in the plot of dynamic heights of isobaric surfaces, but at these latitudes the interpretation is extremely uncertain. Barnes et al. (1948, p. 872) describe what seems to be a similar case in the Marshall Islands area, with regard to a dip in the 10°C. isotherm.

Salinity--The vertical sections of the field of salinity are shown in figures 7, 10, and 14. The major features of the distribution are as described previously for the central Pacific (Cromwell 1951, 1953, 1954; Austin 1954; Montgomery 1954; Mao and Yoshida 1953). The similarity from section to section of *Smith* cruise 14 is self-evident.

The detailed vertical distribution of salinity in the region of 2°-3° N. latitude is of interest and is not readily evident from the sections. Figure 1, illustrating the method of representing the oceanographic stations is taken from *Smith* cruise 14, station 27 at 2°07'N. latitude, 179°57'W. longitude and shows this distribution. The sharp bottom of the thermocline seems to be a boundary between overlying water associated with a salinity minimum extending from the north, in the thermocline, and deeper water with a temperature-salinity relation identical with that of water to the south. The salinity decreases downward through the thermocline, increases sharply across the boundary, then decreases gradually again below; the relative maximum and minimum values lie close together vertically. With the isopleth values used, this feature is most evident on the 180° longitude section. The increase in salinity across the boundary is often accompanied by a stable temperature inversion. Farther to the north the vertical transition below the salinity minimum is more gradual; toward the Equator the salinity minimum disappears into the very salty water extending into the area from the south.

Phosphate phosphorous--The vertical sections of inorganic phosphate for longitudes 180° and 169° W. appear in figures 11 and 15. On the 155° W. longitude line the colorimeter broke down after the first five stations; data for these are tabulated but no figure was drawn. A relatively higher concentration of phosphate about the Equator in the surface layer, seen on the two sections included, is evidence of enrichment from below.

Acknowledgements

Many more persons than can be mentioned here share the credit for the successful completion of Smith cruise 14, and for the publication of this report. The field party personnel during the cruise comprised: Garth I. Murphy (field party chief), E. D. Stroup, H. Yuen, T. Hida, and T. Roseberry. Special thanks must go to Captain Ralph Johnson and the crew of the *Hugh M. Smith* for the utmost cooperation with the scientific field party. Ashore, Mary Lynne Godfrey was largely responsible for the processing of the data. Tamotsu Nakata drafted the figures.

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Figures

Frontispiece: Hydrographic platform and winch, *Hugh M. Smith* cruise 14. Photo by G. I. Murphy.

1. Example of station data representation.
2. Station positions.
3. Dynamic topography, 155° W.
4. Geostrophic currents, 155° W.
5. Vertical section of temperature, 155° W.
6. Vertical section of sigma-t, 155° W.
7. Vertical section of salinity, 155° W.
8. Vertical section of temperature, 180°.
9. Vertical section of sigma-t, 180°.
10. Vertical section of salinity, 180°.
11. Vertical section of phosphate, 180°.
12. Vertical section of temperature, 169° W.
13. Vertical section of sigma-t, 169° W.
14. Vertical section of salinity, 169° W.
15. Vertical section of phosphate, 169° W.
16. Vertical sections of temperature, *John R. Manning* cruise 11.
17. BT traces showing "sharp" thermocline bottom.
18. BT section showing "sharp" thermocline bottom.

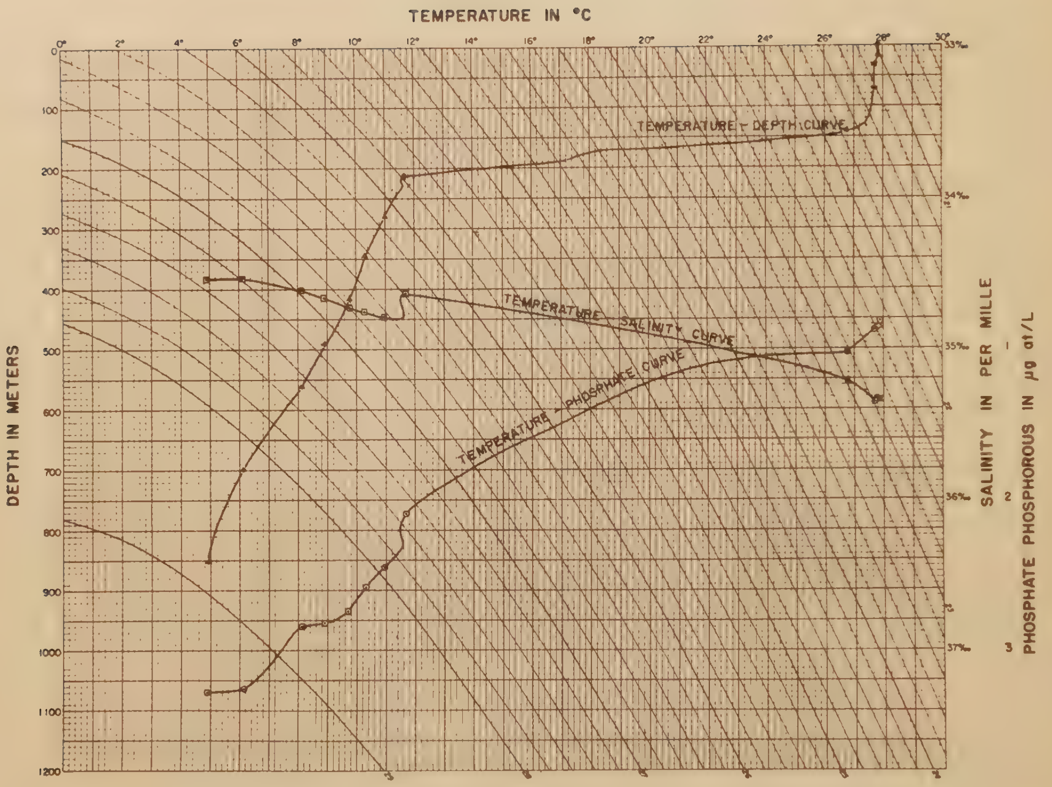

Fig. 1--(Revised from Cromwell 1954). Example of graph used to present temperature, salinity, and phosphate data for each station. Points under inverted V represent reversing thermometer temperatures; plain points are taken from the station BT trace (both plotted against depth). Points in a square represent salinity, and those in a circle phosphate, both plotted against temperature. Smith cruise 14, station 27, 2°07'N. latitude, 179°57'W. longitude, February 19, 1952, 1336 GCT.

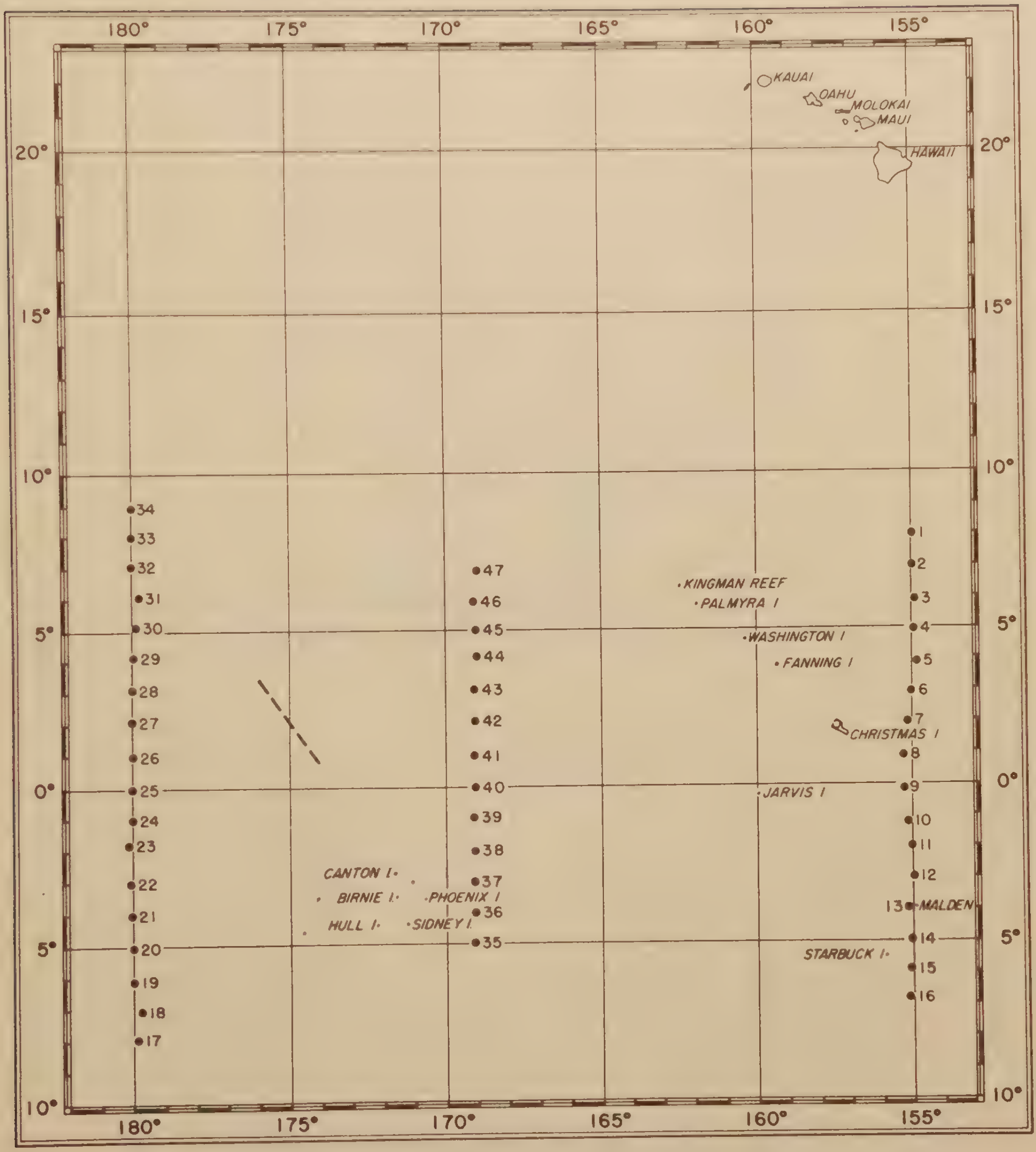

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Fig. 2--Hydrographic station positions. Hugh M. Smith cruise 14, January-March 1952. Location of temperature section in figure 18 indicated by dashed line.

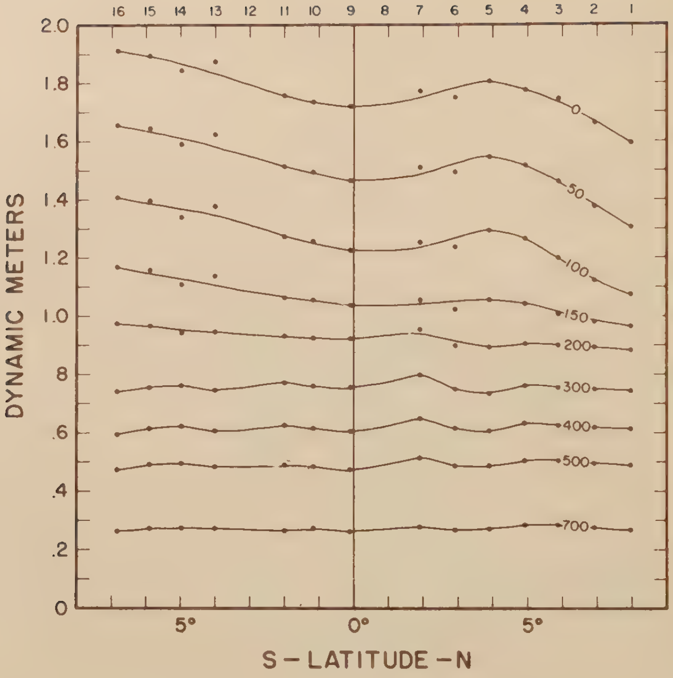

Fig. 3--Smoothed anomaly of topographies of isobaric surfaces relative to the 1,000-decibar surface. Hugh M. Smith cruise 14, stations 1-16, 155° W. longitude, 8° N. to 7° S. latitude, January-February 1952. Points represent computed values.

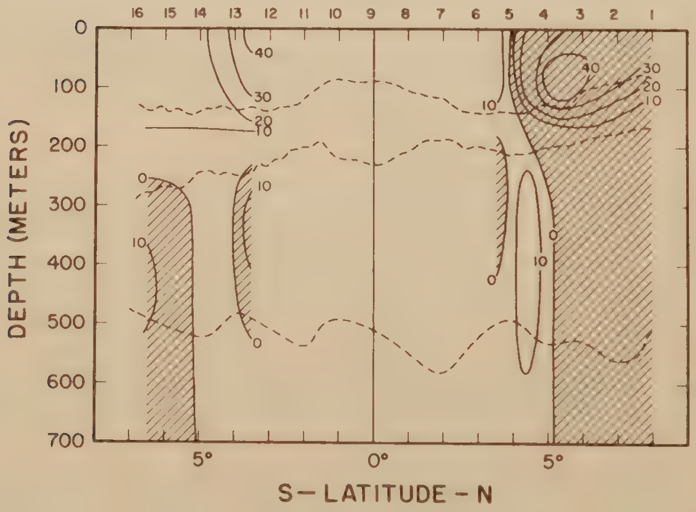

Fig. 4--Zonal component of geostrophic currents in centimeters per second. Hugh M. Smith cruise 14, stations 1-16, 155° W. longitude, 8° N. to 7° S. latitude, January-February 1952. Plotting interval 10 cm/sec. East currents hatched. Isopleths of sigma-t = 23.2, 26.4 and 27.0 entered as dashed lines.

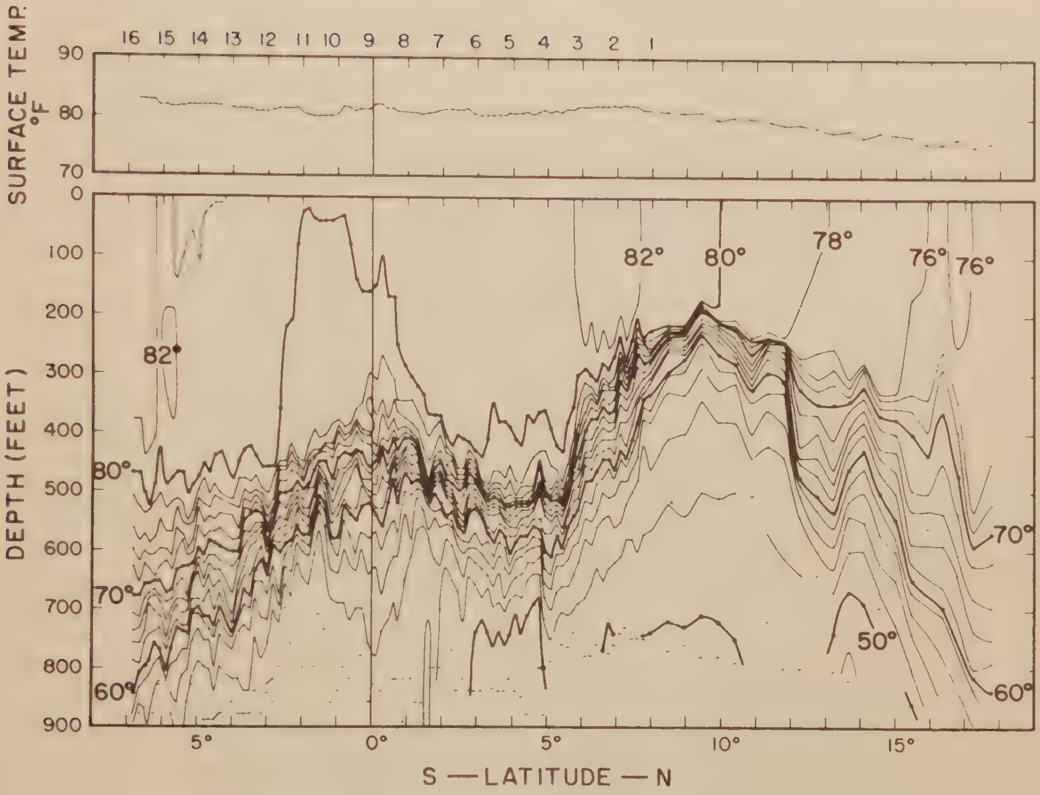

Fig. 5--Upper: surface temperatures by bucket thermometer in degrees F., measured with each BT cast. Lower: temperatures from BT data in degrees F. Hugh M. Smith cruise 14, stations 1-16, 155° W. longitude, 8° N. to 7° S. latitude, January-February 1952. Plotting interval 2° F. Horizontal dashes indicate depths of observations less than 900 feet.

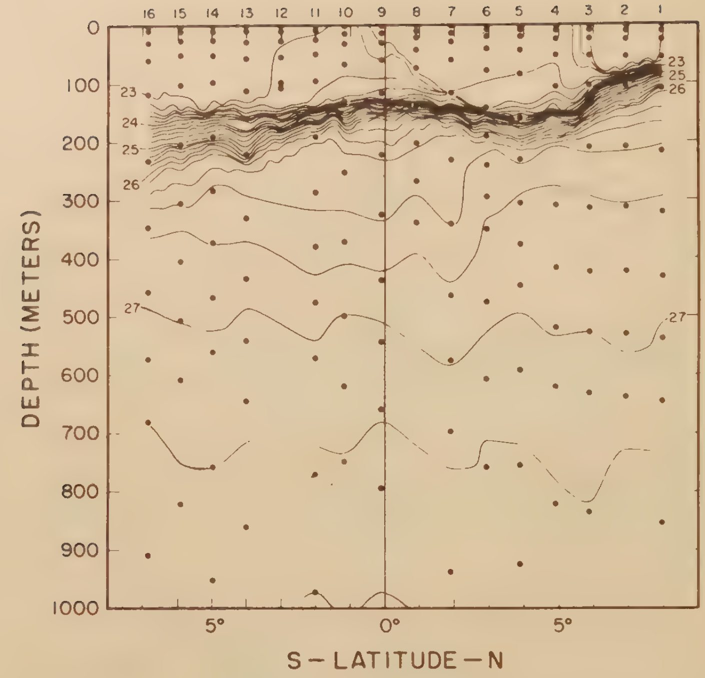

Fig. 6--Sigma-t in grams per liter. *Hugh M. Smith* cruise 14, stations 1-16, 155° W. longitude, 8° N. to 7° S. latitude, January-February 1952. Plotting interval 0.2 g/l.

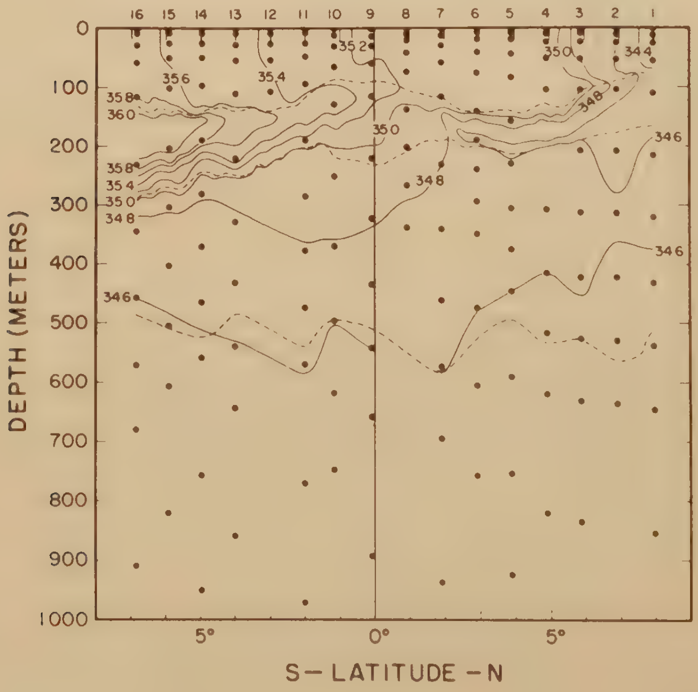

Fig. 7--Salinity in per mille. *Hugh M. Smith* cruise 14, stations 1-16, 155° W. longitude, 8° N. to 7° S. latitude, January-February 1952. Plotting interval 0.2 °/oo. Isopleths of sigma-t = 23.2, 26.4 and 27.0 entered as dashed lines.

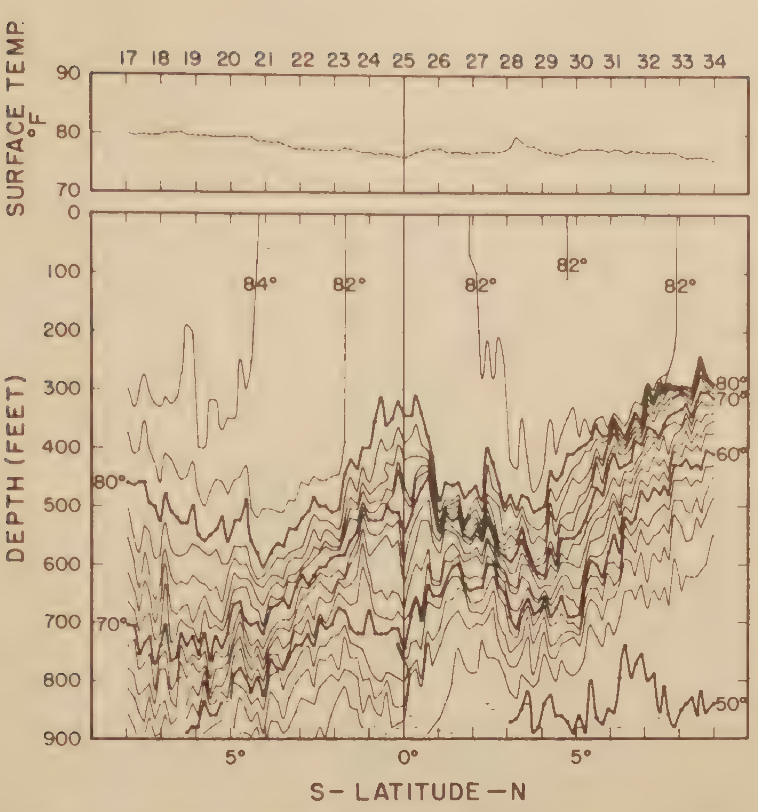

Fig. 8--Upper: surface temperatures by bucket thermometer in degrees F., measured with each BT cast. Lower: temperatures from BT data in degrees F. *Hugh M. Smith* cruise 14, stations 17-34, 180° longitude, 8° S. to 9° N. latitude, February 1952. Plotting interval 2° F. Horizontal dashes indicate depths of observations less than 900 feet.

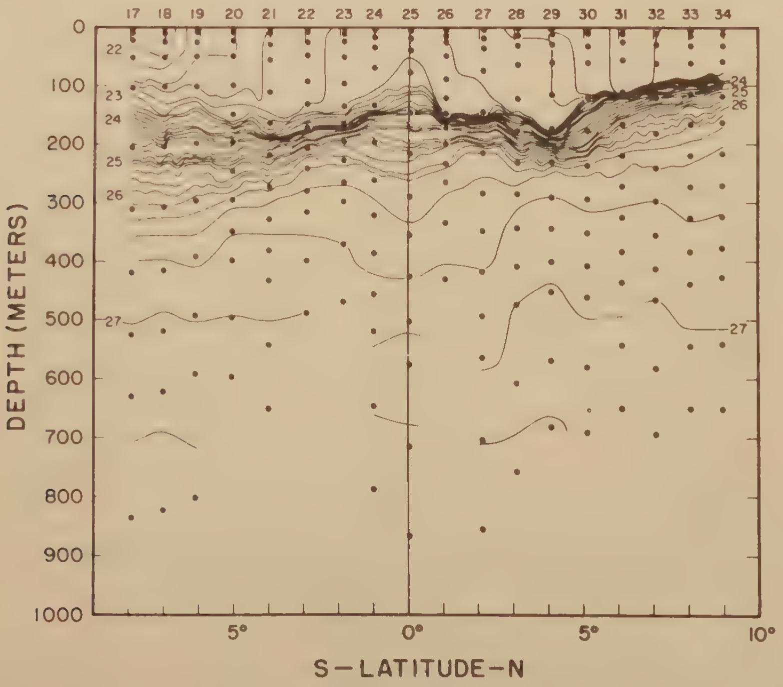

Fig. 9--Sigma-t in grams per liter. *Hugh M. Smith* cruise 14, stations 17-34, 180° longitude, 8° S. to 9° N. latitude, February 1952. Plotting interval 0.2 g/l.

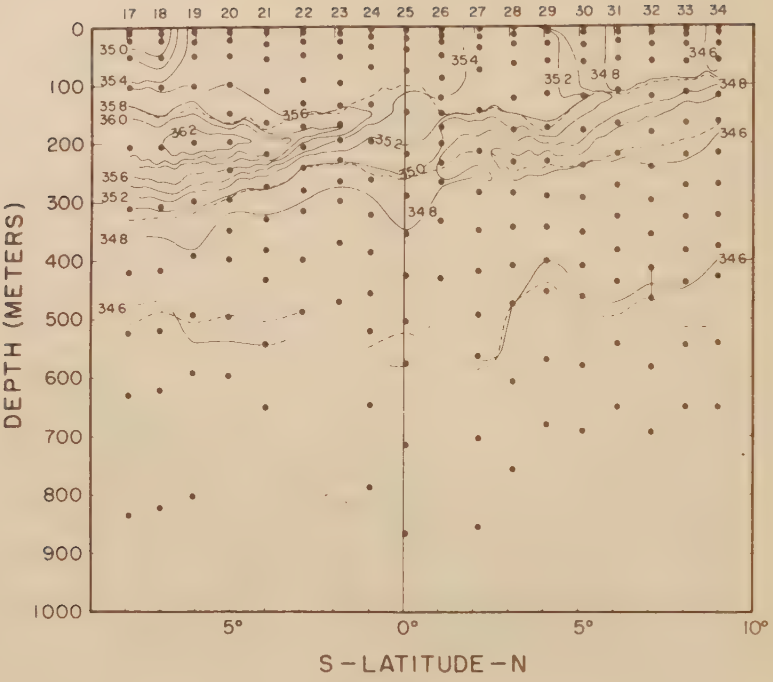

Fig. 10--Salinity in per mille. Hugh M. Smith cruise 14, stations 17-34, 180° longitude, 8° S. to 9° N. latitude, February 1952. Plotting interval 0.2 °/oo. Isopleths of sigma-t = 23.2, 26.4 and 27.0 entered as dashed lines. Solid vertical line indicates vertically isohaline water at the salinity of the intersecting isohaline.

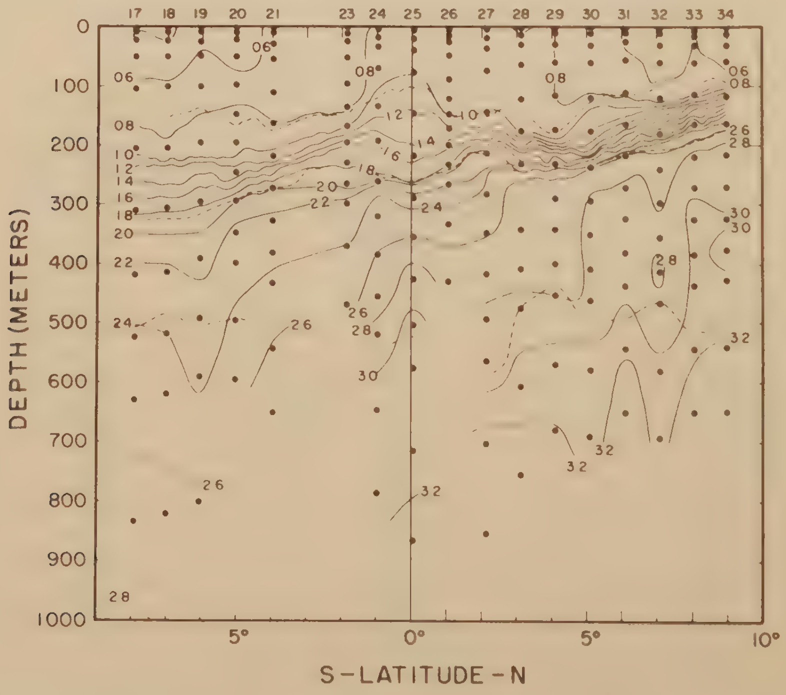

Fig. 11--Phosphate phosphorous in microgram-atoms per liter. Hugh M. Smith cruise 14, stations 17-34, 180° longitude, 8° S. to 9° N. latitude, February 1952. Plotting interval 0.2 µg-at/l. Isopleths of sigma-t = 23.2, 26.4 and 27.0 entered as dashed lines.

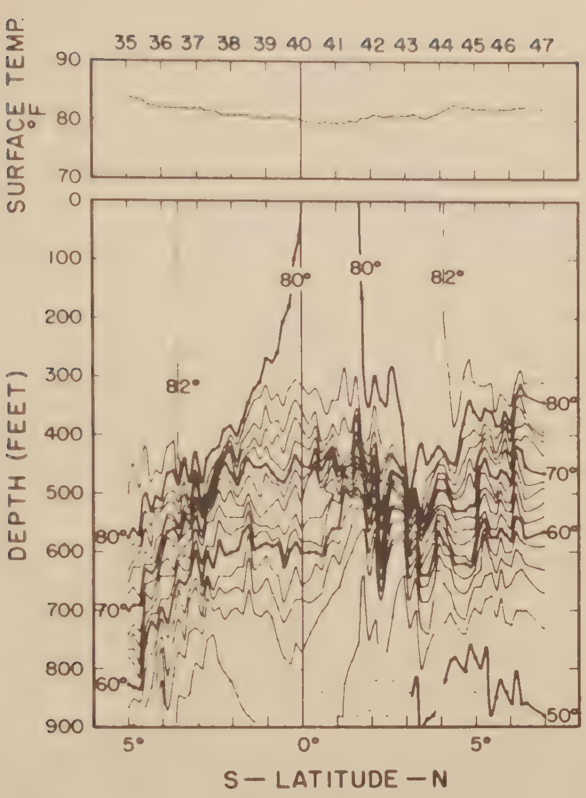

Fig. 12--Upper: surface temperatures by bucket thermometer in degrees F., measured with each BT cast. Lower: temperatures from BT data in degrees F. Hugh M. Smith cruise 14, stations 35-47, 169° W. longitude, 5° S. to 7° N. latitude, March 1952. Plotting interval 2° F. Horizontal dashes indicate depths of observations less than 900 feet.

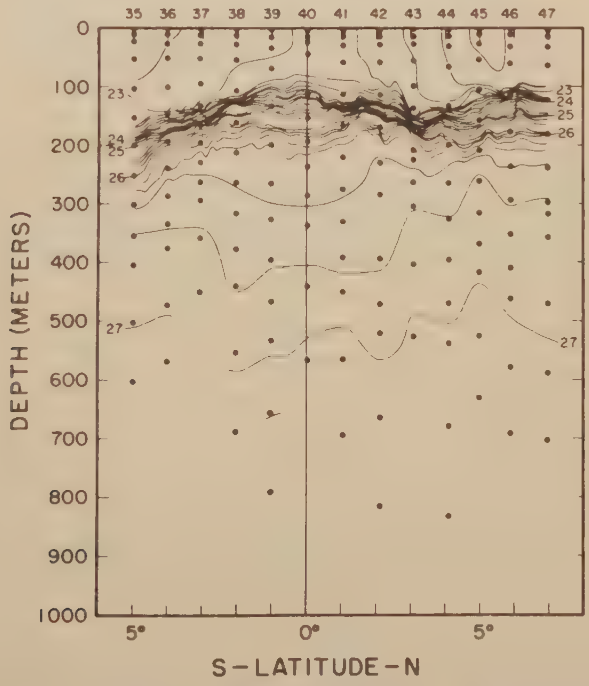

Fig. 13--Sigma-t in grams per liter. Hugh M. Smith cruise 14, stations 35-47, 169° W. longitude, 5° S. to 7° N. latitude, March 1952. Plotting interval 0.2 g/l.

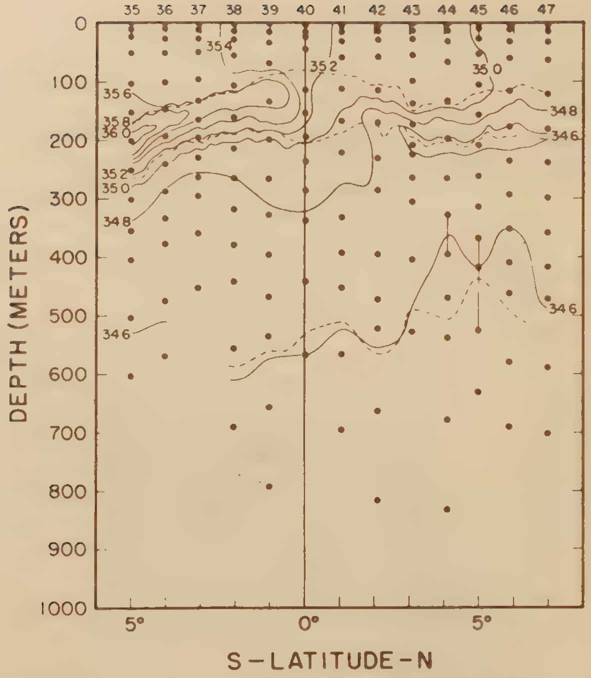

Fig. 14--Salinity in per mille. Hugh M. Smith cruise 14, stations 35-47, 169° W. longitude, 5° S. to 7° N. latitude, March 1952. Plotting interval 0.2 °/oo. Isopleths of sigma-t = 23.2, 26.4 and 27.0 entered as dashed lines. Solid vertical line indicates vertically isohaline water at the salinity of the intersecting isohaline.

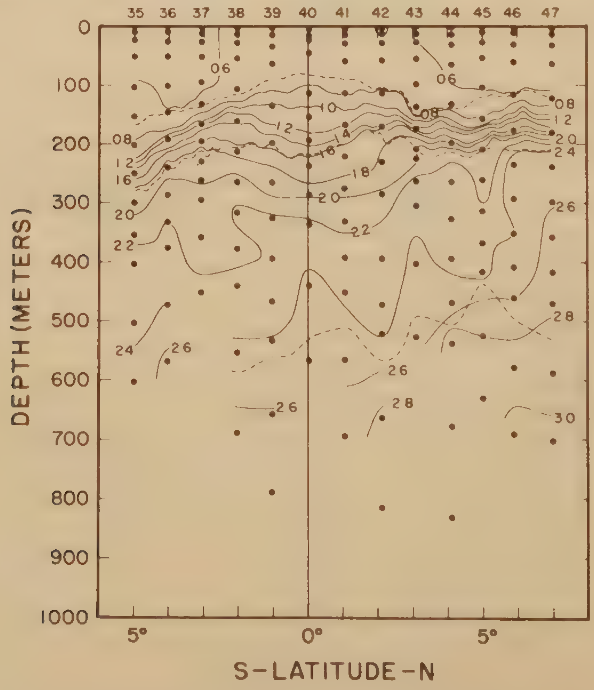

Fig. 15--Phosphate phosphorous in microgram-atoms per liter. Hugh M. Smith cruise 14, stations 35-47, 169° W. longitude, 5° S. to 7° N. latitude, March 1952. Plotting interval 0.2 μg-at/l. Isopleths of sigma-t = 23.2, 26.4, and 27.0 entered as dashed lines.

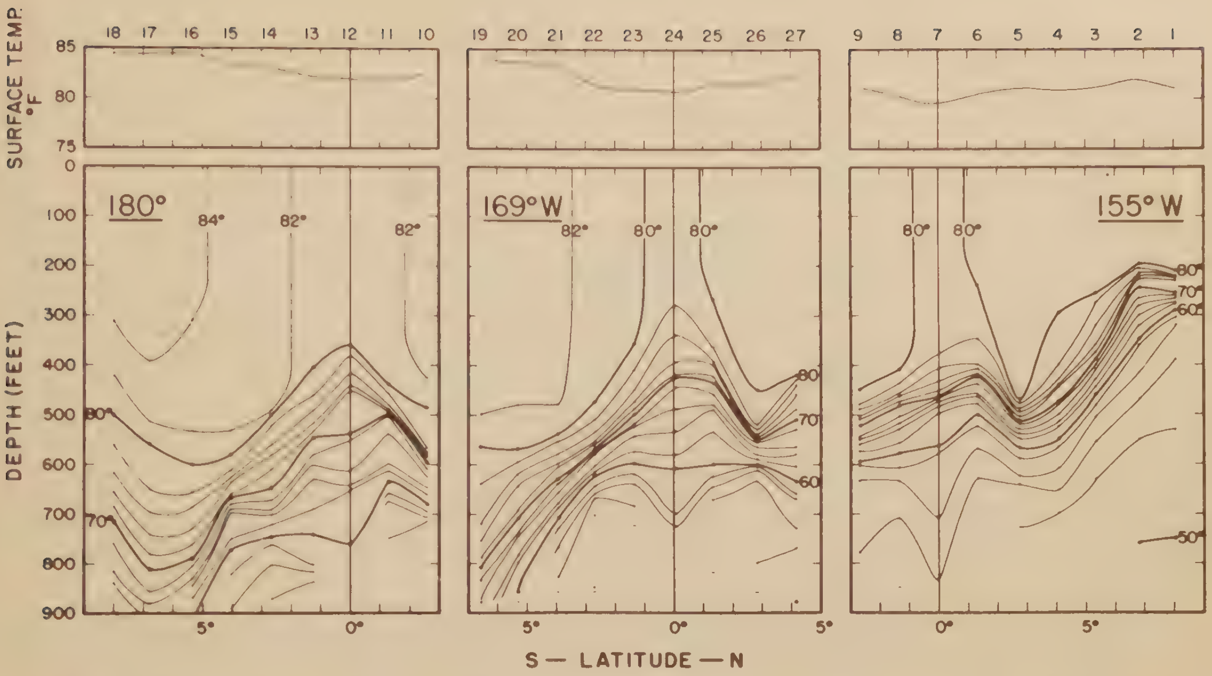

Fig. 16--Upper: surface temperatures by bucket thermometer in degrees F., measured with each BT cast. Lower: temperatures from BT data in degrees F. John R. Manning cruise 11. Right: stations 1 (January 29) - 9, 155° W. longitude, 8° N. to 2°40'S. latitude, January-February 1952. Center: stations 19 (March 4) - 27, 169° W. longitude, 6°40'S. to 4°10'N. latitude, March 1952. Left: stations 10 (February 16) - 18, 180° longitude, 2°35'N. to 8° S. latitude, February 1952. Plotting interval 2° F. Horizontal dashes indicate depths of observations less than 900 feet.

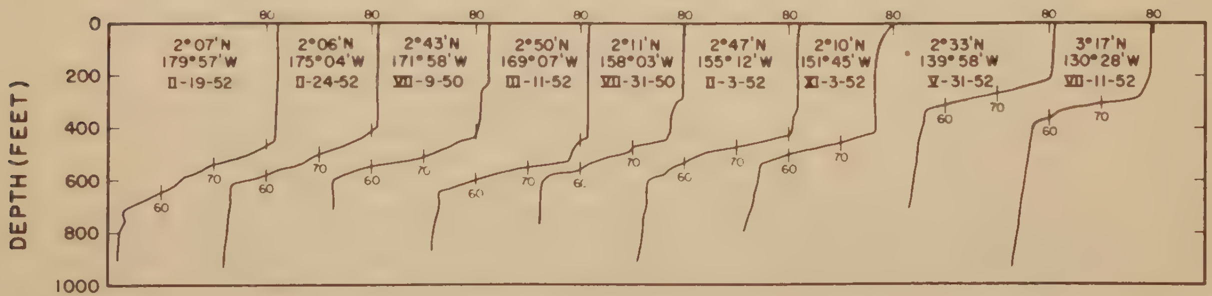

Fig. 17--BT traces illustrating the "sharp" thermocline bottom, 2°-3° N. latitude. Temperatures in degrees F., depths in feet. Position and date of each trace indicated.

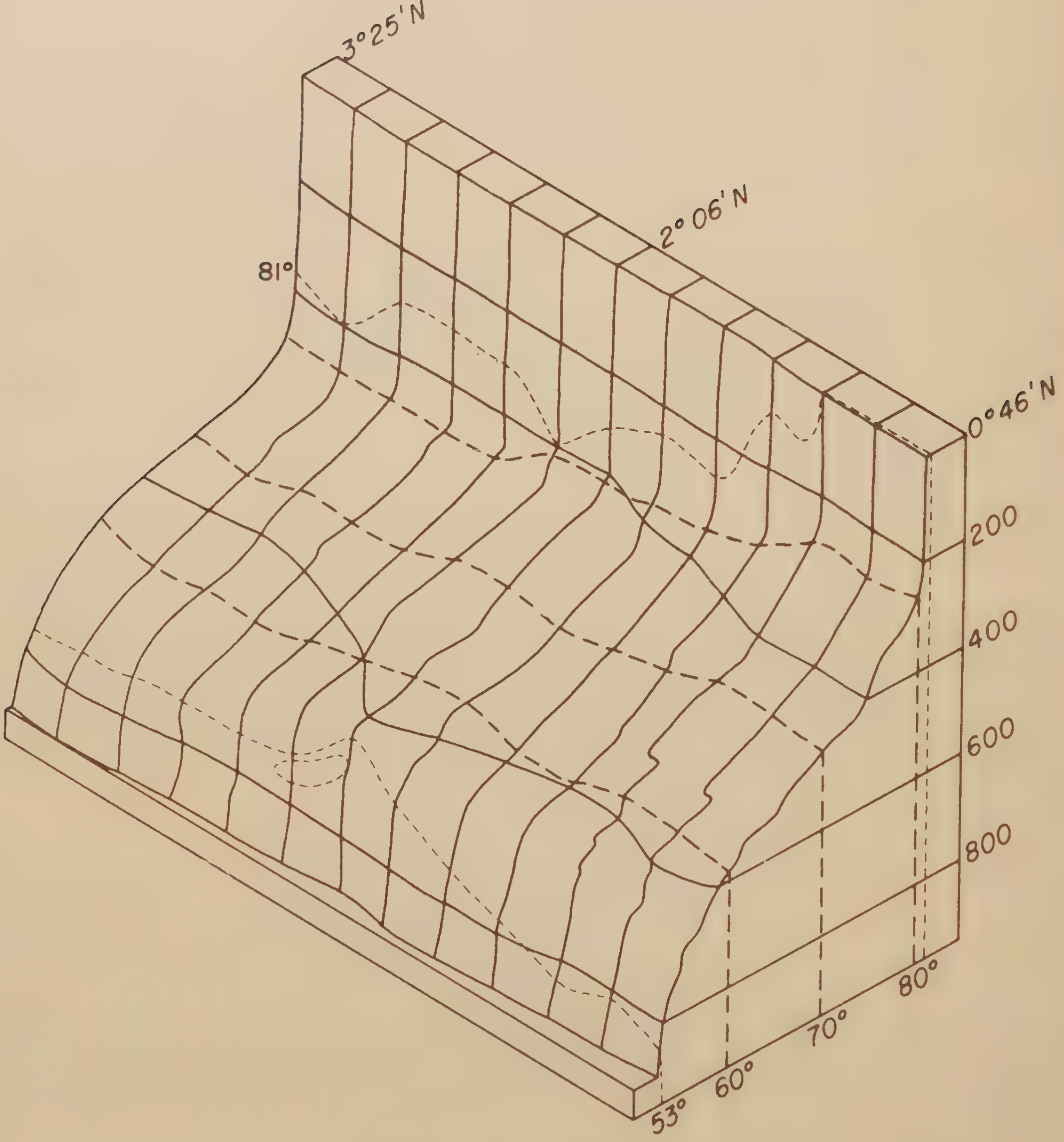

Fig. 18--Isometric block diagram presenting BT traces, 3°25'N. latitude, 175°57'W. longitude to 0°46'N. latitude, 174°05'W. longitude, Hugh M. Smith cruise 14. Depth in feet, temperature in degrees F.

NOTES ON THE TABULATED DATA

In every case, any variation from the standard 13-bottle cast has been explained in a footnote.

Where more than one cast was made on a station, they are divided in the observed data by a horizontal line. The later casts are the deeper ones except on station 34, where a single bottle was recast.

Where the corrected paired protected thermometer readings differed by more than 0.05° C., the depth and salinity are repeated, and both temperature values are carried. Sigma-t values calculated using each temperature are tabulated.

Where the duplicate determinations of inorganic phosphate differ in extinction value by more than 0.01 (approximately 0.05 µg at/l), the depth is repeated, and both phosphate values are carried.

Weather is recorded in the ww (present weather) code given in the U. S. Weather Bureau Circular M, eighth edition, Manual of Marine Meteorological Observations. Cloud coverage is given in tenths of sky.

Wind velocity was measured with an anemometer 30 meters above the sea surface. The direction (given to the nearest 10°) is that from which the wind was blowing, measured clockwise through 360° from north.

No phosphate determinations were made from station 6 to station 16, and no data interpolated at standard depths for dynamic computations after station 19 (see text).

STATION 1

M/V *Hugh M. Smith*: Cruise 14, 7°57'N, 154°57'W, January 27, 1952. Messenger time: 2103 GCT. Weather: 03, cloud coverage 7. Wind: 070°, 24 kt. Sea: 5-8 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.43	34.18	21.98		0.39
11	27.44	34.18	21.98		0.45
26	27.40	34.20	22.01		0.45
55	27.17	34.29	22.15		0.61
109	13.35	34.44	25.91		2.31
215	10.25	34.66	26.66		2.34
321	09.16	34.63	26.82		2.48
432	08.39	34.56	26.89		2.63
538	07.35	34.53	27.02		2.85
646	06.45	34.47	27.10		3.02
853	05.04	34.52	27.31		3.24
1064	04.14	34.51	27.40		3.05
1266	03.54	34.54	27.49		2.93

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.43	34.18	21.98	0.000	1.595
10	27.42	34.18	21.99	0.058	1.537
20	27.42	34.19	22.00	0.117	1.478
30	27.40	34.20	22.01	0.175	1.420
50	27.20	34.27	22.13	0.291	1.304
75	25.10	34.51	22.96	0.424	1.171
100	15.58	34.46	25.45	0.518	1.077
150	11.94	34.49	26.23	0.629	0.966
200	10.61	34.63	26.57	0.713	0.882
250	09.79	34.66	26.74	0.786	0.810
300	09.35	34.65	26.81	0.853	0.742
400	08.62	34.58	26.87	0.982	0.613
500	07.71	34.54	26.98	1.105	0.490
600	06.87	34.49	27.06	1.220	0.376
700	06.03	34.48	27.16	1.326	0.269
800	05.33	34.51	27.27	1.423	0.173
1000	04.41	34.52	27.38	1.595	0.000

STATION 2

M/V Hugh M. Smith: Cruise 14, 6°55'N, 154°57'W, January 28, 1952. Messenger time: 0647 GCT. Weather: 80, cloud coverage 10. Wind: 030°, 22 kt. Sea: 5-8 ft. Wire angle: 17°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.93	34.65	22.18		0.34
11	27.96	34.60	22.13		0.32
11					0.32
25	27.94	34.60	22.13		0.36
53	27.96	34.59	22.12		0.47
105	20.08	34.74	24.56		0.72
209	10.24	34.55	26.58		2.32
313	09.18	34.62	26.81		2.56
423	08.34	34.57	26.91		2.79
423					2.86
530	07.63	34.50	26.96		2.97
637	06.79	34.52	27.09		3.08
1052	04.38	34.50	27.37		3.24
1/					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.93	34.65	22.18	0.000	1.663
10	27.95	34.60	22.13	0.057	1.606
20	27.95	34.60	22.13	0.114	1.549
30	27.95	34.60	22.13	0.171	1.492
50	27.96	34.59	22.12	0.286	1.378
75	27.61	34.68	22.30	0.427	1.236
100	21.00	34.77	24.34	0.542	1.121
150	12.70	34.53	26.11	0.683	0.981
200	10.38	34.55	26.55	0.770	0.893
250	09.78	34.58	26.68	0.844	0.819
300	09.29	34.61	26.79	0.913	0.750
400	08.50	34.59	26.89	1.043	0.620
500	07.89	34.52	26.93	1.166	0.497
600	07.06	34.51	27.05	1.283	0.380
700	06.24	34.52	27.16	1.390	0.273
800	05.50	34.53	27.27	1.487	0.176
1000	04.48	34.50	27.36	1.663	0.000

1/ Two bottles pretripped, but were not recast.

STATION 3

M/V Hugh M. Smith: Cruise 14, 5°53'N, 154°55'W, January 28, 1952. Messenger time: 1708 GCT. Weather: 02, cloud coverage 1. Wind: 040°, 22 kt. Sea: 8-12 ft. Wire angle: 19°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
01	27.84	34.65	22.20		0.40
09	27.87	34.66	22.20		0.45
09					0.37
24	27.82	34.63	22.20		0.39
53	27.73	34.74	22.31		0.40
105	26.16	35.09	23.07		0.70
209	10.66	34.62	26.56		2.43
313	09.16	34.64	26.83		2.49
423	08.45	34.61	26.92		2.66
527	07.65	34.55	26.99		2.94
632	06.85	34.56	27.11		2.98
835	05.92	34.52	27.20		3.10
1039	04.40	34.54	27.40		3.18
1237	03.74	34.56	27.48		3.07
1237					3.21

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.84	34.65	22.20	0.000	1.744
10	27.87	34.66	22.20	0.056	1.688
20	27.84	34.64	22.20	0.113	1.631
30	27.80	34.65	22.22	0.169	1.575
50	27.76	34.73	22.29	0.281	1.463
75	27.22	34.95	22.63	0.417	1.327
100	26.40	35.08	22.99	0.544	1.200
150	17.00	34.73	25.32	0.736	1.008
200	11.00	34.62	26.50	0.844	0.900
250	10.01	34.63	26.68	0.919	0.825
300	09.30	34.64	26.81	0.988	0.756
400	08.58	34.62	26.91	1.116	0.628
500	07.92	34.57	26.97	1.237	0.507
600	07.05	34.56	27.09	1.351	0.393
700	06.60	34.55	27.14	1.457	0.287
800	06.15	34.53	27.19	1.560	0.184
1000	04.67	34.54	27.37	1.744	0.000

STATION 4

M/V *Hugh M. Smith*: Cruise 14, 4°55'N, 154°51'W, January 29, 1952. Messenger time: 0227 GCT. Weather: 02, cloud coverage 1. Wind: 060°, 22 kt. Sea: 8-12 ft. Wire angle: 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σt (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.25	35.08	22.72		0.77
10	27.26	35.07	22.71		0.71
10					0.63
24	27.17	35.04	22.71		0.78
24					0.64
52	27.02	35.04	22.76		0.60
105	26.71	35.16	22.95		0.79
207 1/	10.84				
309	09.26	34.65	26.82		2.29
309					2.52
416	08.70	34.60	26.87		2.71
518	07.99	34.58	26.97		2.91
620	07.14	34.57	27.08		3.13
821 2/	05.79	34.52	27.22		2.84
821	05.82	34.52	27.22		3.14
1027	04.60	34.54	27.38		3.27
1027	04.60	34.54	27.38		2.91
1225	03.84	34.55	27.46		2.52
1225					2.20

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σt (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.25	35.08	22.72	0.000	1.775
10	27.26	35.07	22.71	0.051	1.723
20	27.20	35.04	22.71	0.103	1.672
30	27.10	35.04	22.74	0.155	1.620
50	27.02	35.04	22.76	0.257	1.518
75	26.89	35.14	22.88	0.384	1.391
100	26.77	35.16	22.94	0.509	1.266
150	22.00	34.94	24.19	0.729	1.046
200	11.90	34.62	26.33	0.869	0.906
250	09.64	34.65	26.76	0.946	0.829
300	09.30	34.65	26.81	1.013	0.762
400	08.79	34.61	26.87	1.142	0.633
500	08.10	34.58	26.95	1.267	0.508
600	07.28	34.57	27.06	1.383	0.392
700	06.57	34.54	27.14	1.491	0.284
800	05.90	34.52	27.21	1.592	0.183
1000	04.74	34.53	27.35	1.775	0.000

1/ Phosphate and salinity values are not good; temperature seems all right.

2/ Both the temperature and phosphate duplicates were out of tolerance for this observation.

STATION 5

M/V Hugh M. Smith: Cruise 14, 3°54'N, 154°51'W, January 29, 1952. Messenger time: 1128 GCT. Weather: 02, cloud coverage 1. Wind: 040°, 15 kt. Sea: 5-8 ft. Wire angle: 38°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.17	35.14	22.79		0.72
08	27.20	35.17	22.80		0.73
20	27.18	35.14	22.78		0.75
44	27.19	35.14	22.78		0.69
84	27.07	35.12	22.80		0.35
159	23.61	34.98	23.76		0.44
230	10.80	34.61	26.53		2.02
305	09.16	34.62	26.82		2.16
376	08.75	34.61	26.87		2.26
447	08.26	34.60	26.94		2.50
592	06.88	34.52	27.08		2.83
592	06.93	34.52	27.07		
755	05.77	34.52	27.22		2.78
925	04.88	34.52	27.33		2.73

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.17	35.14	22.79	0.000	1.801
10	27.19	35.16	22.80	0.051	1.751
20	27.18	35.14	22.79	0.102	1.700
30	27.18	35.14	22.79	0.152	1.649
50	27.16	35.14	22.79	0.254	1.547
75	27.10	35.12	22.80	0.382	1.420
100	26.98	35.11	22.83	0.509	1.292
150	24.10	35.01	23.64	0.745	1.056
200	13.71	34.58	25.94	0.907	0.894
250	10.00	34.63	26.68	0.996	0.805
300	09.17	34.62	26.81	1.064	0.737
400	08.57	34.61	26.90	1.192	0.609
500	07.68	34.56	27.00	1.312	0.489
600	06.85	34.52	27.08	1.425	0.376
700	06.13	34.52	27.18	1.529	0.272
800	05.45	34.52	27.26	1.625	0.176
1000 1/	04.62	34.52	27.36	1.801	0.000

1/ Extrapolated values.

STATION 6

M/V Hugh M. Smith: Cruise 14, 2°56'N, 154°59'W, January 29, 1952. Messenger time: 2023 GCT. Weather: 02, cloud coverage 4. Wind: 040°, 19 kt. Sea: 5-8 ft. Wire angle: 47°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.10	35.08	22.77		
08	27.12	35.07	22.75		
20	27.07	35.08	22.77		
41	27.07	35.08	22.77		
77	27.07	35.07	22.77		
141	26.76	35.11	22.90		
190	12.59	34.58	26.17		
240	10.39	34.69	26.66		
295	10.06	34.69	26.72		
350	09.43	34.67	26.81		
475	08.53	34.61	26.91		
475	08.60	34.61	26.89		
607	06.86	34.54	27.10		
758	05.62	34.51	27.23		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.10	35.08	22.77	0.000	1.750
10	27.10	35.07	22.76	0.051	1.699
20	27.07	35.08	22.78	0.102	1.648
30	27.07	35.08	22.78	0.153	1.597
50	27.07	35.07	22.77	0.255	1.495
75	27.07	35.07	22.77	0.383	1.367
100	26.98	35.09	22.82	0.511	1.239
150	20.10	34.83	24.63	0.724	1.026
200	11.62	34.62	26.38	0.851	0.899
250	10.28	34.69	26.68	0.930	0.820
300	09.97	34.69	26.73	1.000	0.750
400	09.18	34.66	26.84	1.135	0.615
500	08.14	34.58	26.94	1.260	0.489
600	06.96	34.54	27.08	1.376	0.374
700	06.07	34.52	27.19	1.480	0.270
800 1/	05.40	34.52	27.27	1.575	0.175
1000 1/	04.58	34.52	27.36	1.750	0.000

1/ Extrapolated values.

STATION 7

M/V Hugh M. Smith: Cruise 14, 1°54'N, 155°03'W, January 30, 1952. Messenger time: First cast 0655 GCT, second cast 0729 GCT. Weather: 50, cloud coverage 10. Wind: 050°, 18 kt. Sea: 5-8 ft. Wire angle:[1] First cast 58°, second cast 40°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/1)	O_2 (ml/1)	PO_4-P (μg at/1)
00	27.40	35.11	22.71		
13	27.42	35.10	22.68		
29	27.38	35.08	22.68		
59	27.32	35.11	22.72		
117	25.00	35.07	23.41		
231	11.40	34.80	26.56		
341	10.81	34.70	26.60		
463	09.32	34.68	26.84		
575	08.08	34.61	26.98		
696	06.58	34.52	27.12		
938	04.83	34.51	27.33		
938	04.85	34.51	27.33		
1209	03.74	34.54	27.47		
[2]					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/1)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.40	35.11	22.69	0.000	1.770
10	27.41	35.11	22.69	0.052	1.718
20	27.40	35.09	22.68	0.103	1.666
30	27.38	35.08	22.68	0.155	1.614
50	27.34	35.11	22.71	0.259	1.511
75	27.30	35.11	22.73	0.388	1.381
100	27.22	35.11	22.75	0.518	1.252
150	16.62	34.80	25.47	0.711	1.058
200	11.76	34.83	26.52	0.815	0.954
250	11.37	34.80	26.57	0.893	0.876
300	11.13	34.75	26.58	0.971	0.799
400	10.10	34.68	26.70	1.120	0.650
500	08.96	34.66	26.88	1.256	0.513
600	07.71	34.58	27.01	1.379	0.391
700	06.50	34.52	27.13	1.490	0.279
800	05.64	34.51	27.23	1.591	0.179
1000	04.58	34.52	27.36	1.770	0.000

[1] Under way to reduce wire angle.

[2] Bottom bottle pretripped, but was not recast.

STATION 8

M/V *Hugh M. Smith*: Cruise 14, 0°54'N, 155°11'W, January 30, 1952. Messenger time: First cast 1638 GCT, second cast 1726 GCT, third cast 1811 GCT. Weather: 01, cloud coverage 1. Wind: 020°, 13 kt. Sea: 3-5 ft. Wire angle: First cast 50°, 1/ second cast 55°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.25	35.06	22.70		
10	27.26	35.03	22.68		
21	27.24	35.04	22.69		
42	27.22	35.06	22.71		
74	27.04	35.06	22.77		
139	19.00	34.82	24.90		
202	12.72	34.88	26.37		
267	11.66	34.84	26.54		
338	10.43	34.74	26.69		
2/					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.25	35.06	22.70		
10	27.26	35.03	22.68		
20	27.24	35.04	22.69		
30	27.23	35.05	22.70		
50	27.20	35.06	22.72		
75	27.04	35.06	22.77		
100	26.17	35.18	23.14		
150	16.80	34.96	25.55		
200	12.83	34.88	26.35		
250	11.88	34.85	26.52		
300	11.07	34.79	26.62		
400 3/	09.48	34.67	26.80		
4/					

1/ Underway to reduce wire angle on cast No. 1

2/ Temperature and depths uncertain below this. Bottles were malfunctioning because of large wire angle.

3/ Extrapolated values.

4/ Observations too shallow to allow extrapolation.

STATION 9

M/V Hugh M. Smith: Cruise 14, 0°06'S, 155°14'W, January 31, 1952. Messenger time: 0421 GCT. Weather: 02, cloud coverage 4. Wind: 060°, 8 kt. Sea: < 1 ft. Wire angle:1/ 48°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
02	27.31	35.04	22.67		
14	27.14	35.04	22.72		
30	26.96	35.07	22.80		
60	26.68	35.23	23.01		
116	25.35	35.26	23.45		
222	13.04	34.97	26.38		
324	11.46	34.82	26.57		
437	09.30	34.67	26.83		
543	07.51	34.60	27.05		
659	06.31	34.54	27.17		
894	04.94	34.55	27.35		
894	04.89	34.55	27.36		
1145	03.83	34.56	27.47		
2/					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.31	35.04	22.67	0.000	1.720
10	27.20	35.04	22.71	0.052	1.669
20	27.05	35.05	22.76	0.103	1.617
30	26.96	35.07	22.81	0.154	1.566
50	26.79	35.18	22.94	0.254	1.466
75	26.50	35.25	23.09	0.376	1.344
100	25.89	35.26	23.28	0.495	1.225
150	18.60	35.08	25.20	0.682	1.038
200	13.43	35.00	26.32	0.798	0.923
250	12.60	34.93	26.44	0.884	0.837
300	11.83	34.86	26.53	0.966	0.755
400	10.00	34.71	26.74	1.115	0.605
500	08.20	34.62	26.97	1.245	0.475
600	06.85	34.56	27.11	1.358	0.362
700	06.00	34.54	27.21	1.459	0.261
800	05.39	34.55	27.30	1.552	0.168
1000	04.43	34.55	27.40	1.720	0.000

1/ Underway to reduce wire angle.

2/ Bottom bottle pretripped, but was not recast.

STATION 10

M/V Hugh M. Smith: Cruise 14, 1°10'S, 155°08'W, January 31, 1952. Messenger time: 1405 GCT. Weather: 02, cloud coverage 2. Wind: 030°, 6 kt. Sea: < 1 ft. Wire angle: 25°

OBSERVED

DEPTH (m)	T (^{o}C)	S (^{o}/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	26.87	35.31	23.02		
14	26.72	35.29	23.05		
32	26.64	35.31	23.09		
66	26.56	35.32	23.12		
129	25.55	35.47	23.55		
252	11.72	34.85	26.54		
371	10.80	34.79	26.67		
498	07.94	34.61	27.00		
620	06.69	34.54	27.12		
749	05.93	34.52	27.20		
1015	04.40	34.53	27.39		
1015	04.45	34.53	27.39		
1293	03.44	34.60	27.54		
1585	03.02	34.59	27.58		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (^{o}C)	S (^{o}/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	26.87	35.31	23.02	0.000	1.735
10	26.77	35.29	23.03	0.048	1.687
20	26.70	35.29	23.05	0.097	1.639
30	26.65	35.30	23.08	0.145	1.590
50	26.60	35.32	23.11	0.241	1.494
75	26.52	35.33	23.14	0.361	1.375
100	26.13	35.41	23.32	0.478	1.257
150	21.70	35.39	24.62	0.679	1.057
200	13.88	35.02	26.24	0.810	0.925
250	11.83	34.86	26.53	0.896	0.840
300	11.41	34.83	26.58	0.974	0.761
400	10.12	34.75	26.76	1.121	0.615
500	07.88	34.61	27.01	1.248	0.488
600	06.83	34.55	27.11	1.359	0.377
700	06.18	34.52	27.17	1.462	0.273
800	05.62	34.52	27.24	1.560	0.176
1000	04.48	34.53	27.38	1.735	0.000

STATION 11

M/V Hugh M. Smith: Cruise 14, 2°00'S, 155°03'W, January 31, 1952. Messenger time: 2124 GCT. Weather: 01, cloud coverage 1. Wind: 020°, 11 kt. Sea: < 1 ft. Wire angle: 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.10	35.27	22.91		
08	26.87	35.26	22.98		
25	26.68	35.26	23.04		
49	26.72	35.29	23.05		
95	26.66	35.34	23.10		
191	14.17	35.12	26.26		
286	11.51	34.83	26.57		
379	10.76	34.79	26.67		
476	08.93	34.69	26.91		
571	07.73	34.61	27.03		
771	05.61	34.52	27.24		
771	05.65	34.52	27.24		
973	04.54	34.56	27.40		
1178	03.79	34.56	27.47		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.10	35.27	22.91	0.000	1.757
10	26.93	35.26	22.96	0.049	1.708
20	26.74	35.26	23.02	0.098	1.659
30	26.68	35.28	23.05	0.147	1.610
50	26.73	35.30	23.05	0.244	1.514
75	26.71	35.33	23.08	0.365	1.393
100	26.62	35.36	23.13	0.485	1.272
150	22.35	35.46	24.49	0.694	1.064
200	13.38	35.05	26.37	0.825	0.932
250	11.89	34.87	26.53	0.908	0.850
300	11.42	34.83	26.58	0.986	0.771
400	10.39	34.76	26.72	1.134	0.623
500	08.62	34.67	26.94	1.267	0.490
600	07.38	34.59	27.06	1.384	0.373
700	06.23	34.53	27.17	1.490	0.267
800	05.46	34.52	27.26	1.587	0.171
1000	04.41	34.56	27.41	1.757	0.000

STATION 12

M/V Hugh M. Smith: Cruise 14, 3°00'S, 154°58'W, February 1, 1952. Messenger time: 0647 GCT. Weather: 21, cloud coverage not recorded. Wind: 000°, 11 kt. Sea: < 1 ft. Wire angle: 27°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.37	35.35	22.88		
10	27.34	35.34	22.89		
27	27.08	35.35	22.97		
54	27.04	35.39	23.02		
108	27.13	35.44	23.03		
1/					

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.37	35.35	22.89		
10	27.34	35.34	22.88		
20	27.21	35.34	22.93		
30	27.07	35.36	22.99		
50	27.07	35.38	23.00		
75	27.07	35.40	23.02		
100	27.12	35.44	23.03		
2/					

1/ Cast pretripped below this.

2/ Observations too shallow to allow extrapolation.

STATION 13

M/V Hugh M. Smith: Cruise 14, 4°00'S, 155°07'W, February 1, 1952. Messenger time: First cast 1548 GCT, second cast 1617 GCT. Weather: 15, cloud coverage 7. Wind: 040°, 14 kt. Sea: 1-3 ft. Wire angle: First cast 17°, second cast 20°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.65	35.55	22.94		
09	27.69	35.53	22.92		
28	27.64	35.52	22.92		
56	27.54	35.53	22.96		
112	27.60	35.56	22.96		
222	18.26	35.46	25.58		
330	10.41	34.76	26.71		
434	08.74	34.65	26.91		
541	07.48	34.59	27.05		
646	06.64	34.54	27.13		
861	05.18	34.52	27.30		
861	05.22	34.52	27.29		
1072	04.23	34.54	27.42		
1280	03.56	34.56	27.50		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.65	35.55	22.94	0.000	1.873
10	27.68	35.52	22.91	0.049	1.824
20	27.68	35.52	22.91	0.099	1.774
30	27.63	35.52	22.93	0.149	1.724
50	27.55	35.52	22.95	0.248	1.625
75	27.56	35.54	22.96	0.371	1.502
100	27.58	35.55	22.96	0.495	1.378
150	26.60	35.71	23.40	0.734	1.139
200	20.82	35.60	25.02	0.924	0.949
250	13.42	35.04	26.36	1.044	0.829
300	11.19	34.83	26.63	1.125	0.748
400	09.22	34.68	26.85	1.265	0.608
500	07.87	34.62	27.02	1.387	0.486
600	06.92	34.56	27.11	1.498	0.375
700	06.20	34.53	27.18	1.601	0.272
800	05.50	34.52	27.26	1.698	0.175
1000	04.56	34.53	27.37	1.873	0.000

STATION 14

M/V Hugh M. Smith: Cruise 14, 4°58'S, 155°00'W, February 2, 1952. Messenger time: 0441 GCT. Weather: 02, cloud coverage 6. Wind: 060°, 18 kt. Sea: 3-5 ft. Wire angle: 32°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.79	35.45	22.82		
09	27.84	35.47	22.82		
26	27.72	35.43	22.83		
51	27.66	35.48	22.89		
90	27.62	35.56	22.96		
191	21.10	35.88	25.15		
283	11.20	34.82 [1]	26.63		
373	09.67	34.70	26.79		
467	08.51	34.63	26.92		
560	07.56	34.58	27.03		
758	05.90	34.51	27.20		
758	05.95	34.51	27.20		
952	04.69	34.51	27.35		
1149	03.99	34.54	27.44		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.79	35.45	22.82	0.000	1.842
10	27.84	35.47	22.82	0.050	1.791
20	27.74	35.45	22.84	0.101	1.741
30	27.70	35.44	22.84	0.151	1.691
50	27.66	35.48	22.89	0.252	1.590
75	27.64	35.50	22.91	0.377	1.465
100	27.62	35.57	22.96	0.501	1.340
150	26.25	35.98	23.71	0.732	1.109
200	18.52	35.63	25.64	0.900	0.942
250	12.62	34.97	26.46	1.002	0.839
300	10.84	34.79	26.66	1.080	0.762
400	09.32	34.68	26.83	1.219	0.623
500	08.14	34.61	26.97	1.344	0.497
600	07.17	34.56	27.07	1.459	0.383
700	06.34	34.52	27.15	1.566	0.276
800	05.60	34.51	27.24	1.665	0.177
1000	04.47	34.52	27.38	1.842	0.000

[1] This sample may possibly have been accidentally contaminated, but appears to be good.

STATION 15

M/V *Hugh M. Smith*: Cruise 14, 5°54'S, 155°03'W, February 2, 1952. Messenger time: 1411 GCT. Weather: 02, cloud coverage 2. Wind: 060°, 18 kt. Sea: 3-5 ft. Wire angle: 32°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.79	35.52	22.87		
09	27.82	35.54	22.88		
26	27.78	35.54	22.89		
51	27.81	35.55	22.89		
102	28.07	35.76	22.96		
204	21.94	36.09	25.08		
305	11.46	34.83	26.58		
404	08.88	34.67	26.89		
507	07.84	34.58	26.99		
608	07.04	34.54	27.07		
822	05.45	34.52	27.26		
1033	04.30	34.54	27.41		
1240	03.66	34.58	27.51		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	27.79	35.52	22.87	0.000	1.898
10	27.80	35.54	22.89	0.050	1.848
20	27.80	35.54	22.89	0.100	1.798
30	27.79	35.54	22.89	0.150	1.748
50	27.81	35.55	22.89	0.250	1.648
75	28.13	35.65	22.86	0.375	1.523
100	28.06	35.76	22.97	0.500	1.398
150	27.22	36.02	23.43	0.738	1.160
200	22.32	36.10	24.98	0.928	0.969
250	15.18	35.30	26.18	1.054	0.844
300	11.64	34.86	26.56	1.141	0.757
400	08.93	34.68	26.90	1.281	0.617
500	07.94	34.58	26.97	1.403	0.495
600	07.10	34.54	27.06	1.517	0.380
700	06.33	34.52	27.15	1.624	0.274
800	05.60	34.52	27.24	1.723	0.175
1000	04.48	34.54	27.39	1.898	0.000

STATION 16

M/V *Hugh M. Smith*: Cruise 14, 6°50'S, 155°05'W, February 2, 1952. Messenger time: 2322 GCT. Weather: 02, cloud coverage 5. Wind: 020°, 13 kt. Sea: 3-5 ft. Wire angle: 12°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.49	35.75	22.82		
10	28.48	35.76	22.83		
30	28.40	35.76	22.86		
59	28.35	35.76	22.87		
118	28.18	35.76	22.93		
233	19.69	35.92	25.56		
347	09.94	34.72	26.76		
458	08.22	34.61	26.95		
573	06.82	34.53	27.09		
682	06.02	34.52	27.19		
910	04.81	34.52	27.34		
1132	04.10	34.54	27.43		
1344	03.54	34.54	27.49		

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	$\Delta D_{1000} - \Delta D$ (dyn. m)
00	28.49	35.75	22.82	0.000	1.911
10	28.48	35.76	22.83	0.050	1.860
20	28.44	35.76	22.84	0.101	1.810
30	28.40	35.76	22.86	0.151	1.760
50	28.38	35.76	22.86	0.252	1.659
75	28.30	35.76	22.89	0.377	1.534
100	28.28	35.76	22.90	0.503	1.408
150	27.18	36.03	23.46	0.742	1.169
200	23.00	36.13	24.81	0.936	0.975
250	17.44	35.62	25.90	1.072	0.839
300	12.42	34.95	26.49	1.168	0.743
400	09.06	34.66	26.86	1.314	0.597
500	07.68	34.57	27.00	1.436	0.475
600	06.63	34.53	27.12	1.546	0.365
700	05.87	34.52	27.21	1.647	0.264
800	05.25	34.52	27.29	1.740	0.171
1000	04.50	34.53	27.38	1.911	0.000

STATION 17

M/V *Hugh M. Smith*: Cruise 14, 7°56'S, 179°53'W, February 15, 1952. Messenger time: 1236 GCT. Weather: 03, cloud coverage 3. Wind: 040°, 8 kt. Sea: 1-3 ft. Wire angle: 13°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	29.58	34.90	21.81		0.35
09	29.60	34.89	21.80		0.44
23	29.42	34.90	21.87		0.46
52	29.36	35.15	22.08		0.45
104	28.36	35.60	22.75		0.69
207	22.86	36.07	24.80		0.94
311	13.54	34.97	26.28		1.76
420	09.23	34.68	26.85		2.26
525	07.52	34.56	27.02		2.41
630	06.54	34.52	27.13		2.47
835	05.11	34.50	27.29		2.72
835	05.15	34.50	27.28		
1044	04.28	34.53	27.40		2.81
1245	03.72	34.53	27.46		2.66

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	29.58	34.90	21.82	0.000	2.037
10	29.60	34.89	21.80	0.060	1.976
20	29.50	34.90	21.84	0.120	1.916
30	29.41	34.94	21.90	0.180	1.857
50	29.37	35.13	22.06	0.297	1.739
75	29.18	35.29	22.24	0.440	1.596
100	28.49	35.55	22.67	0.576	1.460
150	26.20	35.96	23.71	0.814	1.222
200	23.42	36.09	24.66	1.006	1.031
250	18.59	35.67	25.65	1.152	0.885
300	14.40	35.09	26.19	1.261	0.775
400	09.72	34.71	26.79	1.426	0.611
500	07.84	34.58	26.99	1.552	0.485
600	06.79	34.52	27.09	1.664	0.372
700	06.00	34.51	27.19	1.768	0.269
800	05.32	34.50	27.26	1.863	0.174
1000	04.45	34.52	27.38	2.037	0.000

STATION 18

M/V Hugh M. Smith: Cruise 14, 7°01'S, 179°49'W, February 15, 1952. Messenger time: 2219 GCT. Weather: 02, cloud coverage 4. Wind: 050°, 12 kt. Sea: 1-3 ft. Wire angle: 17°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	29.32	34.91	21.91		0.38
10	29.28	34.90	21.91		0.39
24	29.24	34.94	21.96		0.40
52	29.42	35.10	22.02		0.44
102	28.99	35.51	22.47		0.66
205	23.96	36.19	24.58		0.86
308	14.12	35.06	26.23		1.74
416	09.10	34.66	26.86		2.25
519	07.45	34.57	27.04		2.40
823	05.19	34.50	27.28		2.68
823	05.22	34.50	27.27		
621	06.43	34.51	27.13		2.47
1026	04.26	34.52	27.40		2.80
1223	03.70	34.55	27.48		2.82

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	29.32	34.91	21.91	0.000	2.084
10	29.28	34.90	21.92	0.059	2.025
20	29.26	34.92	21.94	0.118	1.966
30	29.23	34.97	21.99	0.177	1.907
50	29.40	35.08	22.01	0.294	1.790
75	29.25	35.33	22.25	0.437	1.646
100	29.00	35.49	22.45	0.576	1.508
150	28.08	35.77	22.97	0.837	1.247
200	24.45	36.19	24.42	1.052	1.031
250	18.80	35.72	25.64	1.204	0.879
300	14.80	35.15	26.15	1.315	0.769
400	09.55	34.69	26.80	1.481	0.603
500	07.67	34.58	27.01	1.605	0.478
600	06.63	34.52	27.11	1.715	0.368
700	05.90	34.51	27.20	1.817	0.267
800	05.32	34.51	27.27	1.912	0.172
1000	04.39	34.52	27.39	2.084	0.000

STATION 19

M/V Hugh M. Smith: Cruise 14, 6°04'S, 179°59'W, February 16, 1952. Messenger time: 0727 GCT. Weather: 02, cloud coverage 4. Wind: 050°, 17 kt. Sea: 3-5 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	29.37	35.47	22.31		0.47
08	29.40	35.44	22.28		0.49
26	29.34	35.45	22.31		0.52
50	29.12	35.46	22.39		0.65
101	28.81	35.58	22.58		0.67
198	23.88	36.25	24.65		0.86
297	14.15	35.11	26.26		1.76
392	10.34	34.78	26.74		2.12
493	08.20	34.63	26.97		2.28
592	07.16	34.57	27.08		2.37
802	05.32	34.52	27.28		2.63
802	05.35	34.52	27.27		
1013	04.36	34.53	27.40		2.70
1224	03.72	34.57	27.49		2.79

INTERPOLATED AND CALCULATED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (gm/l)	ΔD (dyn. m)	ΔD 1000 - ΔD (dyn. m)
00	29.37	35.47	22.31	0.000	2.010
10	29.40	35.44	22.28	0.055	1.955
20	29.39	35.44	22.29	0.111	1.899
30	29.28	35.45	22.33	0.167	1.844
50	29.12	35.46	22.39	0.277	1.734
75	29.00	35.50	22.46	0.413	1.597
100	28.82	35.58	22.58	0.547	1.463
150	26.91	36.02	23.53	0.792	1.218
200	23.82	36.25	24.66	0.988	1.022
250	18.00	35.61	25.76	1.131	0.879
300	14.08	35.10	26.26	1.236	0.774
400	10.12	34.76	26.76	1.398	0.612
500	08.11	34.62	26.98	1.527	0.483
600	07.09	34.57	27.09	1.640	0.370
700	06.19	34.54	27.19	1.744	0.266
800	05.36	34.52	27.27	1.839	0.171
1000	04.39	34.53	27.39	2.010	0.000

STATION 20

M/V Hugh M. Smith: Cruise 14, 5°03'S, 179°59'W, February 16, 1952. Messenger time: 1705 GCT. Weather: 02, cloud coverage not recorded. Wind: 060°, 14 kt. Sea: 1-3 ft. Wire angle: 22°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	29.14	35.51	22.42		0.51
09	29.18	35.47	22.38		0.51
23	29.15	35.47	22.39		0.58
50	29.18	35.50	22.40		0.58
99	29.03	35.60	22.52		0.61
149	28.01	35.62	22.88		0.84
197	24.54	36.26	24.45		0.90
246	18.00	35.52	25.69		1.35
295	12.58	34.95	26.46		1.97
349	9.90	34.73	26.78		2.25
398	9.10	34.69	26.88		2.32
398	9.05	34.69	26.89		
496	8.00	34.62	27.00		2.43
597	7.12	34.57	27.09		2.56

STATION 21

M/V Hugh M. Smith: Cruise 14, 3°59'S, 179°59'W, February 17, 1952. Messenger time: 0242 GCT. Weather: 01, cloud coverage 2. Wind: 070°, 16 kt. Sea: 3-5 ft. Wire angle: 22°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.76	35.59	22.61		0.64
09	28.74	35.60	22.62		0.64
29	28.59	35.59	22.66		0.64
55	28.59	35.58	22.66		0.64
111	28.62	35.59	22.65		0.64
164	27.59	35.67	23.05		0.82
218	21.76	36.01	25.10		1.01
274	13.55	35.03	26.32		1.95
328	10.35	34.78	26.74		2.23
382	9.30	34.67	26.83		2.32
433	8.78	34.65	26.90		2.44
433	8.82	34.65	26.89		
543	7.60	34.60	27.04		2.61
651	6.54	34.53	27.13		2.71

STATION 22

M/V Hugh M. Smith: Cruise 14, 2°56'S, 180°00'W, February 17, 1952. Messenger time: 1212 GCT. Weather: 02, cloud coverage not recorded. Wind: 050°, 20 kt. Sea: 3-5 ft. Wire angle: 37°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.17	35.55	22.77		1/
09	28.20	35.55	22.76		
25	28.17	35.53	22.76		
48	28.16	35.56	22.78		
92	28.20	35.57	22.78		
132	27.90	35.56	22.87		
171	25.71	35.74	23.70		
206	18.04	35.52	25.68		
241	12.82	34.98	26.43		
280	11.32	34.86	26.63		
315	10.33	34.76	26.73		
315	10.36	34.76	26.72		
399	9.12	34.66	26.85		
488	7.98	34.61	26.99		

1/ Phosphate analysis on this station was faulty.

STATION 23

M/V Hugh M. Smith: Cruise 14, 1°52'S, 179°54'E, February 17, 1952. Messenger time: 2234 GCT. Weather: 02, cloud coverage 2. Wind: 060°, 10 kt. Sea: 1-3 ft. Wire angle: 43°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.00	35.53	22.81		0.68
11	27.92	35.54	22.85		0.68
24	27.88	35.53	22.85		0.70
51	27.90	35.53	22.85		0.70
96	27.92	35.53	22.84		0.69
135	27.92	35.57	22.87		0.71
167	25.64	35.77	23.74		0.99
195	16.90	35.36	25.83		1.59
228	13.64	35.04	26.31		1.76
265	11.41	34.83	26.58		1.89
298	10.62	34.77	26.68		2.25
298	10.66	34.77	26.68		
370	9.85	34.75	26.80		2.41
469	9.04	34.69	26.89		2.55

STATION 24

M/V Hugh M. Smith: Cruise 14, 0°59'S, 179°57'E, February 18, 1952. Messenger time: 0702 GCT. Weather: 02, cloud coverage 2. Wind: 070°, 13 kt. Sea: 1-3 ft. Wire angle: 1/ 35°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	27.74	35.44	22.83		0.84
17	27.62	35.44	22.87		0.92
34	27.56	35.44	22.89		0.88
69	27.56	35.44	22.89		0.96
134	25.93	35.57	23.50		1.15
197	16.53	35.12	25.73		1.57
261	11.74	34.86	26.55		2.13
321	10.92	34.77	26.63		2.50
386	10.25	34.75	26.73		2.61
455	9.31	34.70	26.85		2.74
520	8.42	34.65	26.95		2.85
520	8.45	34.65	26.95		
647	6.44	34.56	27.17		3.12
787	5.24	34.55	27.31		3.13

1/ Underway to reduce wire angle.

STATION 25

M/V Hugh M. Smith: Cruise 14, 0°02'N, 179°59'E, February 18, 1952. Messenger time: 1648 GCT. Weather: 02, cloud coverage not recorded. Wind: 060°, 9 kt. Sea: 1-3 ft. Wire angle: 1/ 27°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.45	35.49	22.96		0.92
20	27.48	35.50	22.96		0.95
39	27.39	35.48	22.97		0.96
76	27.16	35.48	23.05		0.99
146	22.26	35.25	24.35		1.21
217	15.87	35.13	25.90		1.56
289	11.70	34.85	26.55		2.30
355	10.88	34.79	26.65		2.62
426	9.60	34.72	26.79		2.88
503	8.52	34.67	26.95		3.05
576	7.39	34.61	27.08		3.17
576	7.43	34.61	27.07		
715	5.88	34.54	27.23		3.16
866	4.82	34.53	27.35		3.24

1/ Underway to reduce wire angle.

STATION 26

M/V Hugh M. Smith: Cruise 14, 1°03'N, 179°58'W, February 19, 1952. Messenger time: 0346 GCT. Weather: 03, cloud coverage 8. Wind: 090°, 13 kt. Sea: 1-3 ft. Wire angle: 49°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	28.03	35.49	22.77		0.91
15	27.58	35.47	22.91		0.93
26	27.50	35.47	22.93		0.94
49	27.50	35.48	22.94		0.94
88	27.48	35.46	22.93		0.91
121	27.36	35.42	22.94		0.93
148	26.63	35.27	23.06		0.96
172	19.37	34.88	24.85		1.24
200	16.22	35.08	25.78		1.51
233	12.52	34.69	26.27		1.75
266	11.46	34.80	26.55		2.18
333	10.66	34.76	26.67		2.50
430	9.36	34.69	26.84		2.71

STATION 27

M/V Hugh M. Smith: Cruise 14, 2°07'N, 179°57'W, February 19, 1952. Messenger time: 1336 GCT. Weather: 02, cloud coverage not recorded. Wind: 070°, 14 kt. Sea: 3-5 ft. Wire angle: 1/ 25°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
04	27.85	35.34	22.72		0.82
18	27.86	35.35	22.72		0.85
36	27.74	35.34	22.76		0.87
74	27.68	35.36	22.79		0.88
144	26.78	35.22	22.98		1.03
214	11.72	34.63	26.37		2.09
283	10.96	34.79	26.64		2.45
348	10.30	34.75	26.73		2.58
418	9.72	34.73	26.81		2.74
493	8.90	34.66	26.89		2.83
564	8.14	34.61	26.97		2.84
564	8.19	34.61	26.97		
703	6.14	34.53	27.19		3.26
855	4.92	34.53	27.33		3.28

1/ Underway to reduce wire angle.

STATION 28

M/V *Hugh M. Smith*: Cruise 14, 3°06'N, 179°57'W, February 19, 1952. Messenger time: 2237 GCT. Weather: 02, cloud coverage 8. Wind: 100°, 7 kt. Sea: 1-3 ft. Wire angle: 32°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.11	35.22	22.54		0.78
13	28.03	35.23	22.58		0.81
30	28.00	35.27	22.62		0.86
63	28.02	35.31	22.64		0.91
122	27.94	35.29	22.65		0.91
176	22.86	35.00	23.99		0.96
231	12.43	34.55	26.17		2.16
284	9.96	34.64	26.70		2.74
343	9.12	34.68	26.87		2.80
409	8.48	34.63	26.93		2.77
474	7.93	34.61	27.00		2.86
474	7.99	34.61	26.99		
607	6.96	34.56	27.10		3.10
756	5.60	34.55	27.27		3.33

STATION 29

M/V *Hugh M. Smith*: Cruise 14, 4°05'N, 179°55'W, February 20, 1952. Messenger time: 0741 GCT. Weather: 63, cloud coverage 10. Wind: 150°, 11 kt. Sea: 3-5 ft. Wire angle: 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.98	34.89	22.34		0.80
10	28.09	35.23	22.56		0.80
29	28.01	35.25	22.60		0.81
59	28.00	35.25	22.60		0.80
115	28.00	35.25	22.60		0.80
173	27.35	35.17	22.75		0.90
230	11.81	34.55	26.29		2.23
289	9.26	34.61	26.79		2.65
343	8.66	34.61	26.89		2.59
400	8.12	34.60	26.96		2.74
452	7.68	34.58	27.01		2.80
452	7.73	34.58	27.00		
569	6.86	34.56	27.11		3.06
680	6.07	34.55	27.21		3.21

STATION 30

M/V Hugh M. Smith: Cruise 14, 5°06'N, 179°50'W, February 20, 1952. Messenger time: 1637 GCT. Weather: 51, cloud coverage not recorded. Wind: 130°, 5 kt. Sea: 1-3 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.17	34.88	22.27		0.65
10	28.22	34.89	22.26		0.61
31	28.22	34.92	22.28		0.71
60	28.20	34.96	22.32		0.77
120	26.96	35.22	22.92		0.99
177	19.88	34.88	24.72		1.22
236	11.34	34.60	26.42		2.55
293	9.68	34.64	26.74		2.82
351	8.96	34.65	26.87		2.93
408	8.42	34.64	26.95		2.82
461	8.07	34.59	26.96		2.83
461	8.12	34.59	26.95		
579	7.28	34.58	27.07		3.08
691	6.42	34.53	27.15		3.14

STATION 31

M/V Hugh M. Smith: Cruise 14, 6°06'N, 179°44'W, February 21, 1952. Messenger time: 0141 GCT. Weather: 63, cloud coverage 10. Wind: 130°, 12 kt. Sea: 3-5 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.07	34.69	22.16		0.63
10	28.10	34.69	22.15		0.54
25	28.08	34.71	22.17		0.58
55	28.12	34.70	22.15		0.64
110	27.58	34.71	22.33		0.64
165	15.78	34.63	25.53		1.52
218	11.14	34.58	26.44		2.60
271	9.88	34.65	26.72		2.84
324	9.24	34.65	26.83		2.87
382	8.66	34.62	26.89		2.89
436	8.35	34.62	26.94		2.94
436	8.39	34.62	26.94		
543	7.37	34.56	27.04		3.17
650	6.50	34.53	27.14		3.32

STATION 32

M/V *Hugh M. Smith*: Cruise 14, 7°04'N, 179°59'E, February 21, 1952. Messenger time: 1040 GCT. Weather: 02, cloud coverage not recorded. Wind: 080°, 13 kt. Sea: 3-5 ft. Wire angle: 03°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.92[1]	34.70	22.22[1]		0.49
10	27.96	34.68	22.19		0.57
30	27.92	34.70	22.22		0.51
60	27.94	34.70	22.21		0.56
120	20.53	34.87	24.54		0.73
180	13.00	34.51	26.03		1.92
240	10.37	34.60	26.60		2.74
297	9.32	34.64	26.80		2.79
355	8.77	34.63	26.89		2.82
413	8.32	34.60	26.93		2.78
466	7.90	34.60	27.00		2.86
466	7.96	34.60	26.99		
581	7.07	34.55	27.03		3.04
693	6.28	34.52	27.16		3.16

[1] Auxiliary of surface bottle thermometer (a single protected thermometer was used in the surface bottle only) was broken. An average value from nearby bottles in the rack was used for correction; temperature and sigma-t may be in error by 0.01.

STATION 33

M/V *Hugh M. Smith*: Cruise 14, 8°03'N, 179°58'W, February 21, 1952. Messenger time: 1936 GCT. Weather: 14, cloud coverage 8. Wind: 070°, 6 kt. Sea: 3-5 ft. Wire angle: 05°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
05	27.52	34.70	22.35		0.62
15	27.54	34.69	22.33		0.60
31	27.50	34.70	22.35		0.62
60	27.53	34.69	22.34		0.66
113	19.28	34.80	24.81		0.82
165	12.17	34.47	26.17		2.29
219	10.56	34.58	26.55		2.86
272	10.00	34.66	26.71		2.95
325	9.53	34.66	26.78		3.08
383	9.03	34.65	26.86		3.03
437	8.51	34.61	26.91		3.08
437	8.55	34.61	26.90		
544	7.48	34.56	27.03		3.17
650	6.56	34.55	27.14		3.38

STATION 34

M/V Hugh M. Smith: Cruise 14, 8°58'N, 179°55'W, February 22, 1952. Messenger time: first cast 0355 GCT, second cast 0429 GCT. Weather: 20, cloud coverage 9. Wind: 050°, 21 kt. Sea: 5-8 ft. Wire angle: first cast 25°, second cast 15°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.05	34.48	22.34		0.50
10	27.08	34.49	22.33		0.51
30	27.02	34.49	22.35		0.54
58	27.03	34.49	22.35		0.58
116	16.20	34.63	25.44		1.36 1/
162	11.34	34.52	26.36		2.50
215	10.45	34.69	26.65		2.90
270	9.82	34.65	26.73		2.94
323	9.30	34.64	26.81		3.01
376	8.88	34.62	26.86		2.95
427	8.47	34.58	26.89		3.05
427	8.52	34.58	26.88		
540	7.47	34.56	27.03		3.21
650	6.72	34.53	27.11		3.23

1/ This one bottle is second cast.

STATION 35

M/V Hugh M. Smith: Cruise 14, 5°00'S, 168°57'W, March 2, 1952. Messenger time: 0409 GCT. Weather: 02, cloud coverage 2. Wind: 060°, 9 kt. Sea: <1 ft. Wire angle: 18°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	28.89	35.58	22.56		0.48
10	28.38	35.56	22.71		0.51
23	28.31	35.58	22.75		0.50
52	28.29	35.60	22.77		0.50
103	27.70	35.53	22.91		0.66
153	27.52	35.67	23.07		0.70
202	22.54	36.09	24.91		0.84
251	15.90	35.27	26.00		1.49
301	12.02	34.92	26.54		1.92
355	9.83	34.75	26.80		2.13
404	9.08	34.69	26.88		2.30
404	9.12	34.69	26.88		
503	8.08	34.62	26.98		2.36
603	6.70	34.52	27.10		2.48

STATION 36

M/V Hugh M. Smith: Cruise 14, 4°02'S, 168°58'W, March 2, 1952. Messenger time: 1254 GCT. Weather: 00, cloud coverage not recorded. Wind: 060°, 13 kt. Sea: < 1 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.94	35.46	22.78		0.55
09	27.96	35.46	22.77		0.55
27	27.90	35.47	22.80		0.55
52	27.84	35.48	22.83		0.55
101	27.85	35.50	22.84		0.57
147	27.34	25.82	23.25		0.70
193	17.56	35.45	25.74		1.25
240	12.44	34.97	26.50		1.91
287	10.48	34.79	26.72		2.11
334	9.34	34.72	26.78		2.20
377	9.29	34.70	26.86		2.24
377	9.33	34.70	26.85		
474	8.18	34.62	26.97		2.41
569	7.31	34.58	27.06		2.65

STATION 37

M/V Hugh M. Smith: Cruise 14, 3°04'S, 168°59'W, March 2, 1952. Messenger time: 2231 GCT. Weather: 02, cloud coverage 3. Wind: 070°, 14 kt. Sea: 1-3 ft. Wire angle: 45°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.84	35.50	22.84		0.59
12	27.80	35.50	22.86		0.57
26	27.72	35.48	22.87		0.56
51	27.65	35.49	22.90		0.57
95	27.62	35.47	22.89		0.57
133	27.30	35.58	23.08		0.69
166	18.97	35.56	25.47		1.23
196	15.00	35.19	26.14		1.64
230	12.32	34.93	26.49		1.97
263	10.50	34.77	26.70		1.99
295	10.16	34.76	26.76		2.14
295	10.19	34.76	26.75		
359	9.87	34.76	26.81		2.07
452	8.76	34.66	26.91		2.28

STATION 38

M/V Hugh M. Smith: Cruise 14, $2^{\circ}03'$S, $168^{\circ}57'$W, March 3, 1952. Messenger time: first cast 0829 GCT, second cast 0910 GCT. Weather: 00, cloud coverage not recorded. Wind: 080°, 14 kt. Sea: 3-5 ft. Wire angle: 1/ first cast 45°, second cast 45°

OBSERVED

DEPTH (m)	T ($^{\circ}$C)	S ($^{\circ}$/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	27.15	35.26	22.89		0.70
13	27.18	35.26	22.88		0.71
28	27.08	35.26	22.91		0.65
55	27.00	35.28	22.95		0.65
107	27.11	35.54	23.11		0.74
161	18.45	35.51	25.57		1.31
213	12.28	34.93	26.50		1.70
264	11.24	34.80	26.59		2.04
317	10.69	34.76	26.66		2.21
378	10.10	34.73	26.74		2.16
441	9.60	34.68	26.79		2.25
554	8.50	34.64	26.93		2.44
689	6.40	34.55	27.17		2.68

1/ Underway to reduce wire angle.

STATION 39

M/V Hugh M. Smith: Cruise 14, $1^{\circ}02'$S, $168^{\circ}54'$W, March 3, 1952. Messenger time: 1901 GCT. Weather: 02, cloud coverage 1. Wind: 090°, 14 kt. Sea: 3-5 ft. Wire angle: 1/ 25°

OBSERVED

DEPTH (m)	T ($^{\circ}$C)	S ($^{\circ}$/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
02	26.89	35.26	22.97		0.69
15	26.92	35.25	22.95		0.72
34	26.88	35.27	22.98		0.66
69	26.86	35.31	23.02		0.67
134	21.50	35.66	24.88		1.02
199	13.10	35.00	26.39		1.49
266	11.58	34.83	26.55		1.89
327	10.84	34.78	26.65		2.23
395	9.98	34.74	26.77		2.21
467	9.20	34.69	26.86		2.22
534	8.34	34.63	26.95		2.43
534	8.39	34.63	26.94		
657	6.32	34.56	27.19		2.61
790	5.41	34.53	27.28		2.68

1/ Underway to reduce wire angle.

STATION 40

M/V Hugh M. Smith: Cruise 14, 0°01'N, 169°00'W, March 4, 1952.
Messenger time: 0455 GCT. Weather: 02, cloud coverage 1.
Wind: 090°, 16 kt. Sea: 3-5 ft. Wire angle: 1/ 45°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.74	35.29	23.04		0.61
15	26.74	35.28	23.03		0.61
24	26.58	35.28	23.08		0.62
45	26.48	35.29	23.12		0.65
114	22.55	35.21	24.24		0.95
153	18.66	35.23	25.30		1.05
193 3/	15.24	35.10	26.01		1.27
195					
237	12.24	34.88	26.47		1.64
286	11.55	34.84	26.56		1.97
337	10.81	34.78	26.66		2.21
337	10.85	34.78	26.65		
441 4/	9.02	34.67	26.88		2.48
567 4/	7.69	34.60	27.03		2.58
2/					

1/ Underway to reduce wire angle.

2/ Bottle pretripped, but was not recast.

3/ Depth slightly unsure--bottle apparently slipped on wire.

4/ Two bottom bottles had slid to end of wire when raised, but values look all right.

STATION 41

M/V Hugh M. Smith: Cruise 14, 1°03'N, 169°00'W, March 4, 1952.
Messenger time: 1448 GCT. Weather: 00, cloud coverage not recorded.
Wind: 080°, 15 kt. Sea: 5-8 ft. Wire angle: 1/ 37°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
04	26.46	35.16	23.03		0.63
15	26.48	35.17	23.03		0.61
30	26.44	35.16	23.04		0.60
59	26.18	35.19	23.14		0.66
113	25.04	35.16	23.47		0.79
167	16.12	34.97	25.72		1.20
222	12.02	34.85	26.49		1.71
275 2/	11.42	34.80	26.56		1.93
288					
331	10.25	34.73	26.72		2.13
392	9.88	34.70	26.75		2.28
451	9.07	34.66	26.86		2.35
451	9.12	34.66	26.85		
565	7.26	34.58	27.07		2.54
694	5.99	34.52	27.20		2.68

1/ Underway to reduce wire angle.

2/ Bottle slipped on wire, depth unsure. Used 275 m. for drawing temperature curve, but may be wrong.

STATION 42

M/V Hugh M. Smith: Cruise 14, 2°06'N, 168°57'W, March 5, 1952. Messenger time: first cast 0043 GCT, second cast 0144 GCT, third cast 0245 GCT. Weather: 02, cloud coverage 2. Wind: 090°, 16 kt. Sea: 3-5 ft. Wire angle: 1/ first cast 42°, second cast 32°, third cast 35°

OBSERVED

DEPTH (m)	T ($^\circ$C)	S ($^\circ$/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
03	27.02	35.17	22.86		0.59
14	26.94	35.17	22.88		0.59
28	26.87	35.15	22.89		0.62
58	26.82	35.16	22.92		0.67
114	25.08	35.10	23.41		0.84
170	14.03	34.70	25.96		1.52
230	11.04	34.79	26.62		1.86
285	10.72	34.78	26.67		2.04
394	9.81	34.71	26.78		2.29
472	9.18	34.68	26.86		2.34
522	8.46	34.62	26.92		2.39
522	8.50	34.62	26.92		
663	6.74	34.55	27.12		2.83
815	5.22	34.53	27.30		2.85

1/ Underway to reduce wire angle.

STATION 43

M/V Hugh M. Smith: Cruise 14, 3°05'N, 169°00'W, March 5, 1952. Messenger time: first cast 1140 GCT, second cast 1214 GCT. Weather: 00, cloud coverage not recorded. Wind: 130°, 10 kt. Sea: 3-5 ft. Wire angle: first cast 42°, second cast 54°

OBSERVED

DEPTH (m)	T ($^\circ$C)	S ($^\circ$/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (μg at/l)
00	27.16	35.11	22.77		0.63
13	27.18	35.10	22.76		0.58
27	27.16	35.12	22.78		0.61
55	27.08	35.12	22.81		0.64
99	27.03	35.14	22.83		0.68
137	26.81	35.16	22.92		0.70
173	16.07	34.68	25.51		1.32
173					1.38
208	11.20	34.56	26.42		2.03
225	10.92	34.61	26.51		1.97
263	9.91	34.63	26.70		2.27
304	9.73	34.70	26.78		2.38
304	9.76	34.70	26.77		
403	8.70	34.63	26.89		2.41
527	7.56	34.59	27.04		2.56

STATION 44

M/V Hugh M. Smith: Cruise 14, 4°06'N, 168°57'W, March 5, 1952.
Messenger time: 2224 GCT. Weather: 02, cloud coverage 9.
Wind: 040°, 19 kt. Sea: 5-8 ft. Wire angle: 28°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.72	35.05	22.54		0.51
13	27.74	35.07	22.55		0.53
31	27.69	35.07	22.57		0.53
66	27.65	35.09	22.60		0.57
132	26.90	35.12	22.86		0.65
198	13.30	34.59	26.03		1.83
264	9.87	34.63	26.70		2.38
327	9.10	34.60	26.81		2.34
395	8.51	34.60	26.90		2.37
469	7.94	34.56	26.96		2.48
538	7.39	34.55	27.03		2.90
538	7.44	34.55	27.02		
678	6.22	34.50	27.15		2.90
831	5.36	34.51	27.27		2.89

STATION 45

M/V Hugh M. Smith: Cruise 14, 4°59'N, 168°56'W, March 6, 1952.
Messenger time: 0611 GCT. Weather: 02, cloud coverage 9.
Wind: 050°, 18 kt. Sea: 5-8 ft. Wire angle: 25°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
01	27.91	34.85	22.33		0.49
09	27.94	34.85	22.32		0.49
26	27.91	34.85	22.33		0.54
53	28.01	35.04	22.44		0.55
105	26.91	35.07	22.82		0.59
157	20.84	34.88	24.46		0.83
209	11.46	34.54	26.35		2.04
261	9.30	34.66	26.82		2.10
314	8.90	34.69	26.91		2.26
368	8.46	34.60	26.91		2.39
417	8.02	34.60	26.98		2.39
417	8.07	34.60	26.97		
525	7.28	34.60	27.09		2.80
630	6.52	34.54	27.14		2.82

STATION 46

M/V *Hugh M. Smith*: Cruise 14, 5°52'N, 169°00'W, March 6, 1952. Messenger time: 1514 GCT. Weather: 00, cloud coverage not recorded. Wind: 080°, 19 kt. Sea: 5-8 ft. Wire angle: 08°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
00	27.92	34.97	22.42		0.54
11	27.94	34.98	22.42		0.49
31	27.91	34.96	22.41		0.53
60	27.93	34.97	22.42		0.55
116	23.62	34.91	23.71		0.64
177	15.08	34.59	25.66		1.63
235	10.48	34.61	26.58		2.51
293	9.40	34.63	26.78		2.56
351	8.76	34.60	26.86		2.40
409	8.37	34.58	26.91		2.47
462	7.95	34.57	26.97		2.60
462	7.99	34.57	26.96		
578	7.12	34.53	27.05		2.88
690	6.08	34.51	27.18		3.07

STATION 47

M/V *Hugh M. Smith*: Cruise 14, 6°58'N, 168°54'W, March 7, 1952. Messenger time: 0442 GCT. Weather: 21, cloud coverage 10. Wind: 080°, 16 kt. Sea: 8-12 ft. Wire angle: 00°

OBSERVED

DEPTH (m)	T (°C)	S (°/oo)	σ_t (g/l)	O_2 (ml/l)	PO_4-P (µg at/l)
03	27.85	34.90	22.39		0.50
13	27.88	34.88	22.36		0.47
32	27.89	34.97	22.43		0.49
63	27.88	34.95	22.42		0.53
122	23.26	34.96	23.85		0.67
180	14.33	34.63	25.85		1.67
238	10.58	34.69	26.63		2.54
298	9.52	34.69	26.81		2.59
357	8.92	34.66	26.89		2.67
417	8.56	34.67	26.95		2.70
471	8.17	34.61	26.96		2.75
471	8.21	34.61	26.95		
588	7.40	34.55	27.03		2.96
701	6.55	34.52	27.12		3.01

REACTION OF TUNA TO STIMULI, 1953

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UNITED STATES DEPARTMENT OF THE INTERI
FISH AND WILDLIFE SERVI

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

REACTION OF TUNA TO STIMULI, 1953

by

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Special Scientific Report: Fisheries No. 134

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REACTION OF TUNA TO STIMULI, 1953

By

Albert L. Tester, Heeny Yuen, and Michio Takata

INTRODUCTION

During 1951 and 1952, studies of the response of tuna (mostly "little tunny", Euthynnus affinis) to stimuli were conducted in tanks and ponds of the Hawaii Marine Laboratory at Coconut Island, Oahu, under contract (I6fw-13331 and I6fw-18564) between the University of Hawaii and the U. S. Department of the Interior, Fish and Wildlife Service, Pacific Oceanic Fishery Investigations. The results of these studies (Special Scientific Report: Fisheries Nos. 71, 91, and 130) indicated that the most promising line of attack on the immediate practical problem--discovering a means of attracting tuna to within reach of a fishing vessel at sea--was in the field of chemo-reception. It was found that the tuna in the pond responded positively and often violently to extracts of tuna and other fish flesh, viscera, etc.

In June 1953 another contract (14-19-008-2126) was negotiated to pursue these studies further. The testing of materials in the pond was to be continued. Sea tests were to be conducted to observe the response of "wild" tuna not only to extracts, but also to visual stimuli such as lures of various sizes, shapes, and colors, used either alone or in conjunction with extracts.

This report includes the results of this third study. Although the work was conducted mostly from June to October 1953, sea tests extending from January 29 to November 13, 1953, are included.

ACKNOWLEDGMENTS

As in past years, troll fishing to stock the ponds with tuna was conducted under the skillful direction of Mr. Lester Zukeran, skipper of the University of Hawaii research vessel Salpa. Mr. Eugene Nakamura and Mr. Royden Ikeda, students, assisted in both fishing and sea testing with this vessel. Mr. Charles Nakamoto, assistant to the Hawaii Marine Laboratory, again was responsible for the feeding and care of the captive fish.

We are again indebted to Mr. Raoul Pantaleoni of E. I. Du Pont de Nemours & Company, to Dr. Ernst T. Theimer of van Ameringen-Haebler, Inc., to Mr. George H. Zirkel of P. R. Dreyer, Inc., and to Mr. R. E. Horsey of Sindar Corporation for supplying many of the chemical compounds which were tested in the pond. In particular, we are grateful to Mr. Fritz Jermann of Hawaiian Tuna Packers Ltd. for preparing most of the extracts which were tested at sea.

The staff of the Pacific Oceanic Fishery Investigations cooperated to the utmost. Special thanks are due Mr. O. E. Sette, Director, and Mr. D. L. McKernan and Dr. W. F. Royce for advice and assistance. Not only were the two research ships Charles H. Gilbert and Hugh M. Smith made available for sea testing, but also many of the staff members conducted or assisted in conducting the sea tests, including D. L. McKernan, J. Slipp, D. Yamashita, H. Mann, and T. Otsu.

The senior author, who directed the investigation, assumes responsibility for the compilation of this report and for the analysis and interpretation of the data which are included. Most of the sea testing was undertaken by the second author; most of the pond testing was undertaken by the third author.

POND AND TANK EXPERIMENTS WITH EXTRACTS OF FOOD AND OTHER MATERIALS

Catching and Establishing the Fish

Two little tunny (Euthynnus affinis), originally established during the summer of 1952 in the large Pond No. 5 at Coconut Island (Tester et al. 1954) survived the winter and formed the nucleus of a new population which was established during July and early August 1953. To the two survivors were added 12 tunny and 9 yellowfin (Neothunnus macropterus) at the end of June. As in the previous year, the fish were caught by trolling with the Salpa and were transported in the vessel's livewell to Pond No. 5. Of the 21 fish introduced to the pond only one, a tunny, failed to become established, that is, to start feeding. This great success, compared with that of previous years, is attributed to the presence of the two survivors, which acted as leaders of the new fish.

Mortality among the established tunny was moderate between July 1 and October 1, 1953: 5 of the 13 died, leaving 8 which have survived to the time of writing (January 1954). Although the 9 yellowfin appeared to be in good condition at the time they started feeding, all had died by the middle of September. The reason for this mortality, which took place irregularly throughout the period, is unknown.

Two tunny originally established during the summer of 1952 in a concrete tank (Tester et al. 1954) survived the winter and were used in experiments during the early summer. One jumped from the tank and died on July 19, 1953. The other, which was partially blind, died 3 days later.

Feeding the Fish

From April 25 to July 17, 1953, the tunas in the pond were fed exclusively on frozen squid from the mainland. They were fed 4 times a week (Tuesday, Thursday, Saturday, and Sunday) at a rate of about 2 pounds of squid per fish per week. Following July 17, 1953, they were fed daily for 1 week on squid, 1 week on skipjack flesh, 1 week on frozen shrimp from the mainland, and thereafter 4 times a week on skipjack flesh. The change in diet was associated with experiments (to be discussed later) probing the possibility of food-conditioned responses.

The tunny in the tank were fed on tuna flesh 4 times a week throughout 1952 and until they died in 1953.

Materials and Testing Procedures

One hundred and sixty-nine experiments were conducted during the summer of 1953, 162 in the pond and 7 in the tank. Of these, 94 involved extracts of "natural" foods and the other 75 involved solutions or suspensions of chemical materials. Pertinent data on these tests are included in the appendix to this report. The tests are numbered in sequence with those presented in appendix I of Tester et al. (1954). They are referred to by number in the sections which follow, e.g. #495.

"Natural" foods from which extracts were made included skipjack (Katsuwonus pelamis) flesh, skipjack viscera, skipjack blood, dolphin (Coryphaena hippurus) ovaries, anchovy (Stolephorus purpureus), hammerhead shark (Sphyrna sp.) flesh, mainland squid, mainland shrimp, and marine plankton. The materials were prepared in a similar manner: fish, squid, or shrimp flesh was chopped either by hand or in a grinder, placed in a Waring Blendor and macerated after adding tap water, further diluted with water, and allowed to stand for several hours in a refrigerator. Either the whole extract was tested, or the clear portion was separated by decanting or centrifuging and tested. The procedure was the same for blood and plankton except that the initial chopping was not necessary. A self-digested skipjack viscera preparation supplied by Hawaiian Tuna Packers Ltd. was also used in preliminary tests. In some preparations 95-percent ethyl alcohol, instead of water, was added prior to maceration in the Blendor.

The miscellaneous chemical materials were dissolved or suspended in water before testing, using Tergitol and/or mechanical emulsifier when necessary.

Tank and pond tests were conducted in a similar manner to that of last year (Tester et al. 1954). The only important change involved the pond: the observation tower was moved from the western end to the center of the north side (fig. 1). In brief, testing was conducted as follows: the fish were timed and counted in an attraction area during five 3-minute control periods (2-minute periods in the tank); the test material was introduced from the top of the tower into the attraction area through a stream of water which flowed constantly; and the fish were timed and counted during ten subsequent 3-minute test periods. "Timing" consisted of recording on an electric clock operated by a push switch the number of seconds spent by one or more individuals of the tunny school in the attraction area. The "attraction area" was a portion of the pond in front of the tower which was marked off by two pieces of string stretching across the pond; it was approximately 39 by 75 feet in area. "Counting" consisted of recording on a hand counter the number of passes made by each fish in the attraction area while the fish was moving in either a "down" or "up" (easterly or westerly) direction. Materials introduced through the pipe leading from the top of the tower remained in the attraction area for at least 15 minutes and then gradually dispersed. The time and direction of dispersal was governed by the strength and direction of the weak tidal current. Usually a period of at least 30 minutes was allowed to elapse between the end of one experiment and the start (control conditions) of the next to enable introduced materials to disperse or to become diluted to a level well below the threshold of response.

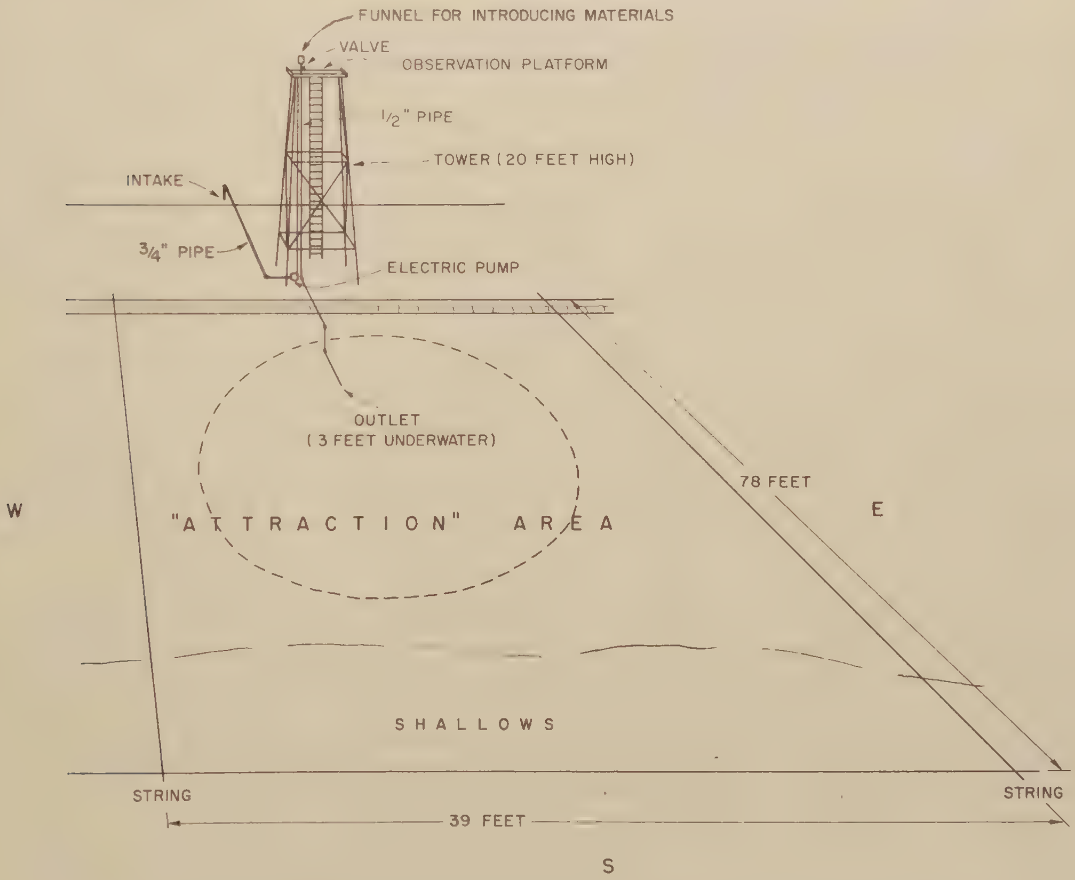

Fig. 1.--Diagram of Pond No. 5 at Coconut Island showing the observation tower, attraction area marked off with string, and the pipes, pump, and funnel used to introduce test materials to the pond.

In addition to obtaining quantitative data in the manner described above, the observer also recorded his visual impression of the strength of the response in one of five categories indicated as "-", an apparent repulsion; "0", no response; "X", a weak positive response; "XX", a moderate positive response; and "XXX", a strong positive response.

Quantitative data were obtained only with the tunny. Yellowfin were also present in the pond, but no attempt was made to measure their reactions because of their erratic behavior. It might be noted, however, that when they did enter the attraction area during an experiment, their response was similar to that of the tunny except that it was generally less pronounced for a given stimulus.

Response to Extracts of "Natural" Food Substances

Although the tunny in Pond No. 5 had been fed exclusively on mainland squid for about 2 months prior to July 1, 1953, before their diet was changed they showed a positive response to extracts of skipjack viscera (#362, but not #357, 358, 363, 368), skipjack flesh (#359, 360, etc., but not #367), skipjack blood (#383), dolphin ovary (#377), anchovy (#384, but not #396), hammerhead shark flesh (#393, but not #373), mainland shrimp (#374, 375), mainland squid (#370, 376, etc.), and marine plankton (#387). The two tunny in the concrete tank, which had been fed exclusively on tuna flesh, showed a positive response to extracts of skipjack flesh (#378, 389), anchovy (#385), mainland shrimp (#382, 386), mainland squid (#380), but not to an extract of hammerhead shark flesh (#392).

In general, the response in the pond was weak and extremely variable as compared with that obtained with extracts of tuna flesh, viscera, etc. in the summer of 1952. To produce responses with tuna flesh extract it was necessary to use about five times as much material as was used in the summer of 1952 (about 100 g. as compared with about 25 g. of flesh). However, the amount used was not as much as was necessary during the spring of 1953 (about 350 g.), when the two surviving tunny were particularly unresponsive (Tester et al. 1954).

The fact that the squid-fed tunny did respond to such a wide variety of extracted food substances (even to plankton in one experiment) indicated that they were not conditioned to the smell or taste of the particular food which was being fed. However, at times, it seemed that the response of the pond tunny to squid extract was more pronounced than that to extracts of other substances.

It was decided to undertake a series of experiments involving three test substances (extracts of squid, skipjack flesh, and shrimp), each to be tested on each of three days per week (Tuesday, Wednesday, and Thursday), the tests to run for 3 consecutive weeks. Prior to and during each successive test period the food was to consist respectively of squid, skipjack flesh, or shrimp. Each week one of these foods was to be fed to the fish at 4 p.m. each day from Thursday (after the Thursday tests were made) to the following Wednesday. The order of testing was to change each day, so that no two tests would appear in the same order on successive days of each week (Latin square design).

Two departures from the plan were made. Due to an error, the same order of testing was used in two of the three days in Week 1. A fourth substance was added to the three primary tests, namely, a blend (equal parts) of squid, skipjack flesh, and shrimp extract. Thus two tests were made in the morning and two in the afternoon of each day. The series either started or ended with the blend, which was either preserved or not preserved with sodium bisulphite. A summary of the results is given in appendix I (#398 to 409; #414 to 425; and #436 to 447). It will be noted that in each test the same method of preparation and the same amount of material was used (100 g. extracted with 2,000 ml. water).

For each test the strength of the response according to the observer's visual impression and also the strength of the response as measured quantitatively is given in table 1. The variate for the latter, which was used for statistical analysis, may be explained by means of an example. In the experiment conducted with an extract of skipjack flesh on Thursday of the second week, when the fish had been fed skipjack flesh (see table 1, $E_2D_3F_2$), the mean time spent by the fish in the attraction area was 7.2 seconds during control periods and 28.6 seconds during test periods, with a mean difference of 21.4 seconds. The mean number of "passes" in the attraction area was 4.4 during control periods and 15.2 during test periods, with a mean difference of 10.8 passes. The differences in both time and count reflect the response, although their relative value as a measure of response is difficult to assess. The two were added, giving 32.2; rounded off, giving 32; and increased by 20, giving 52. The last step, adding 20, was included because in some cases negative differences were obtained, i.e., the fish spent relatively more time and/or made more passes in the attraction area during control than during test periods.

Order of testing is not indicated in table 1. Inspection of the data indicated no consistent trends in response with order of testing within days: on some days the first substance tested gave a high response whereas on other days the last substance tested gave a high response. Similarly, inspection of the data indicated no significant differences between the preserved and non-preserved blend. Accordingly the results were analyzed *in toto* according to three criteria of classification:

(1) **Extract** -- E_1-squid; E_2-skipjack; E_3-shrimp; E_4-blend

(2) **Days** -- D_1-Tuesday; D_2-Wednesday; D_3-Thursday

(3) **Food (= Weeks)** -- F_1-squid; F_2-skipjack; F_3-shrimp

Table 1.--The response of tunny to four extracts (E) on three days (D) in each of three weeks during which they were fed three different foods (F). For further explanation see text.

Food	Days	Extract				Total
		E_1 Squid	E_2 Skipjack	E_3 Shrimp	E_4 Blend	
F_1 squid	(D_1 Tue.)	44(X)	49(XX)	21(X)	62(XXX)	176
	(D_2 Wed.)	29(X)	30(XX)	29(X)	57(XXX)	145
	(D_3 Thurs.)	35(X)	52(XXX)	12(0)	41(XX)	140
		108	131	62	160	461
F_2 skipjack	(D_1 Tue.)	43(XX)	49(XX)	57(X)	24(X)	173
	(D_2 Wed.)	27(X)	56(XX)	34(X)	23(X)	140
	(D_3 Thurs.)	9(0)	52(X)	32(X)	31(XX)	124
		79	157	123	78	437
F_3 shrimp	(D_1 Tue.)	44(XX)	36(XX)	48(X)	27(X)	155
	(D_2 Wed.)	28(X)	32(XX)	36(X)	51(XXX)	147
	(D_3 Thurs.)	5(X)	26(X)	10(0)	23(0)	54
		77	94	94	101	366

The analysis is as follows:

Source of variation	Degrees of freedom	Sum of squares	Mean square
F	2	405.723	202.861
D	2	1304.889	652.444**
E	3	995.334	331.778*
FxD	4	467.944	116.986
FxE	6	2240.499	373.416*
DxE	6	968.000	161.333
FxDxE	12	1139.167	94.930

where * indicates an F value for which P is less than 0.05, and ** indicates an F value for which P is less than 0.01, in all cases using the second order interaction as the error term.

There are no significant differences among the mean responses to the different foods which were fed. However, as shown in the following values of the grand means, there is a general decrease from Week 1 (F_1) to Week 3 (F_3): 38.4, 36.4, 33.2. In view of the results which follow, this trend, if real, is more likely related to time than to food. Of necessity, time (weeks) and food are confounded in the design.

There are highly significant differences in the mean responses of the fish between successive days of the week. As shown by the grand means for successive days, there is a progressive decrease in response from D_1 (Tuesday) to D_3 (Thursday): 42.0, 36.0, 27.3. The decrease is consistent within weeks, as is apparent from the lack of any significant interaction involving days in the analysis of variance table, or as may also be seen from the data of table 1. It may be shown that the regression of response on days is highly significant (mean square for regression is 1290.667**) and accounts for most of the variation between days. A study of tidal heights, direction of tidal current, and weather at the time of each test revealed no apparent relationship to account for the regression. It is most likely due to progressively increasing fatigue or a dulling of response with successive testing. It may reflect a learning process--the fish can be deceived into a feeding reaction by the extract but become less responsive when they find that no food is available[1]. Although the fish were allowed to rest on Saturdays and Sundays, the regression may have been carried over from one week to the next, particularly if it involved a progressive dulling of response or a learning process, thus accounting in part at least for the decrease in response between weeks noted in the preceding paragraph.

There are significant differences in the responses to the various extracts. The grand means for squid, skipjack flesh, shrimp, and blend extracts are respectively as follows: 29.3, 42.4, 31.0, 37.7. According to these results the skipjack flesh extract gave the greatest response and the squid extract the smallest response, with the blend slightly greater than the mean of the other three. Although heterogeneity is indicated, it may not reflect differences in response between the substances per se, but rather an interaction between the extracts and the food fed (no significant differences between the grand means for extracts are indicated if the FxE interaction is used as the error term).

There is a significant first order interaction between extracts and foods (or weeks). This indicates that the fish responded differently to the four extracts when they were fed on different foods (or, in different weeks). The nature of the differential response may be seen from the following summary, which gives the mean response according to both food and extract:

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[1] This has been suspected to occur between successive tests within days on other occasions.

Food (Weeks)	Extract			
	E_1(squid)	E_2(skipjack)	E_3(shrimp)	E_4(blend)
F_1(squid)	36.0	43.7	20.7	53.3
F_2(skipjack)	26.3	52.3	41.0	26.0
F_3(shrimp)	25.7	31.3	31.3	33.7

It is unfortunate that the effect of food cannot be separated from the possible effect of the time component (Weeks), although it is difficult to see how the latter, if a regression, could lead to a significant interaction with extract. The inclusion of the blend extract data has contributed to the interaction. However, the interaction is still significant if these data are excluded from the calculations. The response to squid extract was greatest when the fish were being fed squid. The response to skipjack extract was greatest when the fish were being fed skipjack. The response to shrimp extract was greatest when the fish were being fed skipjack, but it was greater when they were fed shrimp than when they were fed squid. The differential response indicates a degree of conditioning of the fish to a particular food substance. In part, this may explain the weaker responses to skipjack flesh and viscera extracts during July 1953 as compared with the summer of 1952, for in 1953 they were being fed squid whereas in 1952 they were being fed tuna flesh.

On completion of the experiments on conditioning the tunny were fed skipjack flesh three times a week. Additional experiments indicated no significant difference in response between extracts of light red (#469, 473, 478, 484) and dark red (#470, 472, 480, 482) skipjack flesh.

Alcohol extracts of skipjack flesh seemed to elicit a much weaker response than aqueous extracts (see #475 to #489). This was the case when the alcohol extracts were tested without further processing and also when they were evaporated to dryness and redissolved in water. The reason may be that the "attractant" was only partially extracted with alcohol; this was suspected to be true in some of the preparations used in 1952-53 (Tester et al. 1954).

Response to Chemical Compounds

The following chemicals in solution or suspension were tested during the summer of 1953:

Adenylic acid, muscle (#517)
Alanine, alpha DL (#450)
Amyl caproate (#505)
Amyl cinnamate (#372)
Anethol (#427)
Anisic aldehyde (#365)
Arginine monohydrochloride, L (#428)
Asparagine, DL (#426)
Aspartic acid, L (#453)
Aspartic acid, DL (#463)
Astrotone (#515)
Bologna flavor (#411)
Betaine (#474)
Blood fibrin (#523)
Butter flavor (#413)
Butyric acid, alpha amino n (#455)
Cadaverine dihydrochloride (#500)
Calcium pantothenate, D (#493)
Casein (#512, 524)
Casein hydrolysate (#522)
Chlorophyll (#459)
Cholic acid (#496)
Ionine C-1 (#506)
Isoeugenol (#410)
Lactulbumin (#521)
Leucine, DL (#430)
Liver extract concentrate (#499)
Liver fraction "L" (#497)
Lysine monohydrochloride (#466)
Lysine monohydrochloride, L (#451)
Mercaptan, phenyl ethyl (#516)
Methionine (#390)
Musk ambrette (#503)
Musk ketone (#498)
Musk xylol (#504)
Norvaline, DL (#456)
Ornithine monohydrochloride, DL (#468)
Phenylalanine (#491)
Phenyl ethyl alcohol (#509)
Proline, L (#467)
Pyridoxine hydrochloride (#462)
Riboflavin (#510)
Serine, DL (#429)
Sodium bisulphite (#449)

Citral (#371)
Creatinine (#495)
Eucalyptol (#395, 513)
Glutamic acid hydrochloride, L (#519)
Glutamic acid monohydrate, DL (#452)
Glutaric acid, alpha keto (#431)
Gluten (#525)
Glycyl-glycine (454)
Guanine (#435)
Guanine hydrochloride (#464)
Hexahydrobenzoic acid (#518)
Histidine (free base) (#448)
Histidine monohydrochloride, DL (#432)
Hydroxyproline (#433)
Ionine, alpha methyl (#508)
Testosterone (#501)
Threonine, DL (#461)
Threonine, DL, with allothreonine (#460)
Thiamine hydrochloride (#492)
Tonquin musk (#511)
Tryptophane (#434)
Tryptophane, DL (#458)
Tyrosine, DL (#490)
Uracil (#494)
Urami (#465)
Viosterol (irradiated ergosterol) (#507)
Vitamin A, crystalline (#514)
Yeast hydrolysate (#520)
Xanthophyll oil (#457)

There was no positive response to any of the above substances. In a few (#365, 413, 498, 503), activity simulating a response was noted, but this may have been caused by extraneous factors or it may have been a curiosity about or sensing of some of the strong smelling materials. In others of a bright orange color (#510) or a dark green color (#459) there was an avoiding or repellent effect which was obviously visual in origin.

Discussion

In view of the results given in a preceding section which indicate that the response to extracts of "food" substances may be partially conditioned by the particular type of food fed, it seems worthwhile to speculate further on the part which conditioning may play in causing *all* responses in the pond. The so-called "attractant" to tuna may be a complex of substances which are present in one grouping or another, and to a greater or lesser extent, in extracts of many marine animals such as fish, squid, shrimp, or even plankton. Certainly the tuna in the pond have become accustomed to being fed on dead material--so much so that they ignore live bait in the pond. Possibly they have associated the act of feeding with the smell or taste of this "attractant" which is released into the water from the cut-up food material when it is thrown to them at feeding time. Thus they may exhibit a conditioned feeding response when stimulated by this "attractant" which is present in the extract. This would be a possible explanation of why they respond to extracts of one material when another is being fed. In addition, a further conditioning to a particular substance or complex of substances in a particular food organism could conceivably take place. If so, this would explain why they show a heightened response to extracts prepared from the particular food substance which they are being fed. It was hoped that even if this were so, wild fish at sea might be naturally "conditioned" to a smell given off by the whole, live organisms on which they feed, particularly if the organisms were occasionally injured during the feeding process and gave off attractive body juices. More information on the part played by conditioning, natural or otherwise, might be obtained from pond experiments if the tunny would feed on live bait. As they will not do this (unless the bait is caught and thrown to them), the only other obvious way to settle the question is to present the extracts to wild fish at sea and to study their response.

POND EXPERIMENTS WITH EDIBLE LURES

As the tuna in the pond were accustomed to being fed with materials thrown to the surface by an attendant, they showed a strong visual response to objects which suddenly appeared on the surface and also to persons who approached the edge of the pond. This conditioned behavior made it difficult to perform meaningful experiments in the field of visual and visual-chemical stimulation (Hsiao and Tester 1954). Inedible objects such as leaves falling to the surface or stones thrown to the surface would attract the fish if they were within about 50 feet of the object (the tunny have a keen sense of vision). They would dash after such objects, snap at them, and sometimes take them into their mouths but, as nearly as could be observed, would then reject them. It would have been possible to devise experiments to study the response to inedible objects of different materials, buoyancy, size, shape, and color to see if there was any preference, but this was not done for fear that if these artificial lures were made sufficiently attractive to be taken by the fish they might be eaten and would cause their death. To avoid this possibility edible lures were used. A series of 33 pond experiments were conducted over the period from August 18 to October 29, 1953. These are discussed in the following sections.

Materials and Methods of Preparation

In view of the practical problem of attracting tuna to the stern of a fishing vessel, there was need for an edible material which was low in cost, easily prepared, and at the same time both visually and chemically attractive to the fish. In other words it was desired to create a lure which was attractive in shape, size, color, and movement in order to visually attract the fish from a distance, and which at the same time was edible and sufficiently palatable to induce them to want more. Three basic materials were tested: (1) gelatin capsules, (2) macaroni, and (3) agar gelatin.

The gelatin capsules (Eli Lilly & Co., No. 000) were about 1 inch long when closed, and consisted of two parts, the body (about 7/8 inch) and the cap (about 5/8 inch). They gradually softened in water, eventually collapsing and dissolving after several minutes. Unsuccessful attempts were made to impart motion to the whole capsule. A slow motion was imparted to the open-ended body or cap when floating on the surface by (a) gluing pellets of calcium carbide inside the closed end, (b) gluing pellets of "Bromo-seltzer" inside the closed end, and (c) stuffing the body or cap loosely with cotton wool (to form an adsorption surface) and filling with 95-percent alcohol (extract of skipjack flesh) before throwing to the surface of the water. The motion of the first two depended on gas production on contact with sea water for the propelling force; that of the third depended on the affinity of alcohol for water. The motion was very slow, of the order of about 6 inches per second or less. The carbide-filled capsules were not used in the pond for fear of killing the fish.

Some of the gelatin capsules were coated with a sticky glue (plastic in acetone) and were then dusted with aluminum powder (Sirius Commercial Aluminum Compound) to make them silvery in appearance. Others were coated with a gummy concentrate of skipjack extract (boiled to a residue) giving them a brownish color. Still others were coated with both the aluminum and the concentrate. They were tested both with and without the motion imparted by the chemicals.

The precut macaroni ("Royal" or "Golden Grain") was cooked in water, in concentrated skipjack extract, and in concentrated anchovy extract, in some cases both with and without preservative (about 2 percent sodium bisulphite). The cooked pieces were about 3/8 inch in diameter and 1-1/2 inches long.

The amount of extract used in cooking each small batch was adjusted so that all was absorbed by the time the macaroni was cooked to the right consistency. The pieces were then removed from the pot with a spatula and dried on a screen until they were slightly sticky to the touch. Before being used some were coated with corn starch to keep them from sticking together; others were coated with aluminum powder to give them a silvery appearance. Some were plugged at both ends with glue or with small pieces of cotton wool so that they tended to float when thrown to the surface; others, not plugged, would slowly sink.

Agar (common Japanese variety) was purchased in long strips (about 11 x 1 x 1 inches). Both "colorless" and red varieties were used. It was boiled with water (300 ml. to one strip), concentrated skipjack extract, and concentrated anchovy extract, both with and without the addition of aluminum powder and both with and without preservative. The boiled solution was poured into flat pans and set in the refrigerator. It was then removed and sliced into strips approximately 2 x 1/4 x 1/16 inches. Strips thicker than 1/16 inch tended to sink too rapidly; those thinner than 1/16 inch tended to float on the surface of the water.

Method of Testing

In the first experiment, the edible lures were thrown to the fish in the pond from ground level after the school had gathered in front of the observer. As the fish were visually attracted to the observer as well as to the lures this method was abandoned. In all subsequent experiments the lures were thrown to the pond from the tower when the tunny were away from but approaching the attraction area. Generally the fish did not see the splash of the lures as they hit the water, but saw the lures themselves on entering the attraction area. Observations were made of the number of lures which sank before the fish approached (classified as "not seen"), the number presumably visible to the fish but ignored ("ignored"), the number taken into the mouth but rejected or spat out ("rejected"), and the number taken and eaten ("eaten"). Observations were made also on the behavior of the fish, e.g., whether they showed excitement and whether they returned to the attraction area after the lures were presented. In later experiments the response was indicated in the same categories as were used in the experiments with chemical stimulation (0 to XXX).

Each experiment took a considerable period of time (usually about 30 minutes); it could be performed only when the tunas were cruising regularly up and down the pond. Only a few lures (usually three with one observer or up to eight with two observers) could be presented to the fish at one time; if more were used it was difficult to keep track of the ultimate fate of each.

Results

Four experiments were performed with gelatin capsules, using about 12 capsules in each and presenting them two or three at a time to the fish. In the first, the capsules were coated with aluminum powder, plugged with cotton, and motivated with alcohol extract. In the second, they were coated with aluminum powder and extract concentrate, plugged with cotton, and motivated with alcohol extract. In the third, they were coated with aluminum powder and extract concentrate, and motivated with Bromo-seltzer. In the fourth, they were coated with extract concentrate only, and motivated with Bromo-seltzer. In the first experiment, the fish were attracted to the capsules, took them into their mouths, but then rejected them. In the other three experiments they were attracted to and ate all the capsules. Thus it seems that all preparations were visually attractive to the fish, but only those coated with extract concentrate were actually eaten. The small amount of motion imparted to the capsules by the alcohol and Bromo-seltzer appeared to play little or no part in attraction.

In 14 experiments performed with macaroni lure preparations there was no noticeable difference in response to materials which were (1) either preserved in sodium bisulphite, or not; (2) either plugged with cotton wool, or not (although more of the latter sank before being observed by the fish); and (3) either cooked in concentrated skipjack extract or cooked in concentrated anchovy extract. The data grouped into four main categories are included in table 2.

It is noteworthy that the pond fish consumed 54 percent of the plain macaroni lures; however, these were usually eaten only towards the start of a series of experiments. The results suggest that coating with aluminum powder increases the visual attractiveness of the lure, that coating with extract increases its chemical attractiveness or palatability, and that a combination of the two gives the best response, with 95 percent of the lures being eaten. However, only in the comparison of "with aluminum and extract" versus "plain" is the difference in response statistically significant[2].

In 13 experiments with agar lure preparations, there was no noticeable difference in response between preparations with or without the preservative nor between preparations boiled in concentrated skipjack or anchovy extract. Plain red agar strips seemed to be more attractive than plain colorless agar strips, but the difference was not statistically significant. The results grouped in four categories are included in table 2.

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[2] Testing the ratio (ignored plus rejected): (eaten) yields an adjusted Chi-square of 13.8 with one degree of freedom (P less than 0.01).

Table 2.--Summary of the response of tunny to pieces of cooked macaroni and strips of agar in several experiments

Lure and preparation	Number of pieces: Not seen	Ig-nored	Re-jected	Eaten	Total	Percent eaten
Elbow macaroni:						
Plain	(7)	2	9	13	24	54
With aluminum	-	-	4	10	14	71
With extract	(1)	1	3	7	11	64
With aluminum and extract	(4)	1	1	40	42	95
Agar strips:						
Plain	-	3	6	10	19	53
With aluminum	-	2	5	2	9	22
With extract	(2)	1	-	22	23	96
With aluminum and extract	(3)	1	3	11	15	73

The best response, with 96 percent of the lures being eaten, was obtained with agar strips cooked in concentrated extract. As they assumed a brownish color, they may have been visually as well as chemically more attractive than plain colorless agar. The addition of aluminum did not seem to increase the attractiveness of the agar preparations.

A series of tests was conducted to determine if there were any differences in response to (a) macaroni cooked in concentrated skipjack extract and coated with aluminum powder, and (b) agar cooked in concentrated skipjack extract and impregnated with aluminum powder. In both cases the preparations, part of a large quantity used in sea tests, were preserved with 1 percent sodium bisulphite. The lure preparations were presented alternately to the fish, eight pieces at a time. The pairs of tests were repeated several times throughout the morning, and again throughout the afternoon of the same day. The results are shown in tables 3 and 4.

In the morning series (table 3) the tunny ate 69 percent of the macaroni lures and 100 percent of the agar lures. In the afternoon series (table 4) they ate only 10 percent of the macaroni lures but still ate 100 percent of the agar lures. It is obvious from the data, and it was still more obvious from observation, that the pond fish showed a decided preference for the agar lures after the first pair of tests. The percentage of macaroni lures which was eaten gradually decreased with successive testing. In the last three pairs of tests in the afternoon some of the pieces of macaroni were taken into the mouth, but all were rejected; on the other hand all agar strips, if seen, were eaten. Apparently a learning process was involved. In general, the overall reaction (speeding, surfacing, splashing, return to area, etc.) was more pronounced with the agar than with the macaroni lures; the difference was more noticeable in the morning than in the afternoon tests.

Table 3.--Results of experiment (#32--a.m.) with macaroni and agar preparations, eight pieces of each presented alternately in a series of tests

Lure and preparation	Test No.	Number of pieces				Total	Percent eaten	Reaction
		Not seen	Ig-nored	Re-jected	Eaten			
Elbow macaroni:	1	(8)	-	-	-	-	-	XX
	3	-	-	-	8	8	100	XX
plus aluminum and	5	-	-	1	7	8	88	XX
	7	-	1	-	7	8	88	XX
extract	9	-	5	-	3	8	38	X
	11	(pieces not visible due to reflection of sun)					-	XX
	13	-	1	-	7	8	88	X
	15	(8)	-	-	-	-	-	
	17	-	4	-	4	8	50	XX
	18	-	3	-	5	8	62	X
	19	-	5	-	3	8	62	X
Totals		(16)	19	1	44	64	69	
Agar strips:	2	-	-	-	8	8	100	XXX
	4	(1)	-	-	7	7	100	XX
plus aluminum and	6	-	-	-	8	8	100	XX
	8	-	-	-	8	8	100	XX
extract	10	-	-	-	8	8	100	XX
	12	-	-	-	8	8	100	XX
	14	-	-	-	8	8	100	XX
	16	-	-	-	8	8	100	XX
Totals		(1)	-	-	63	63	100	

Table 4.--Results of experiment (#33--p.m.) with macaroni and agar preparations, eight pieces of each presented alternately in a series of tests

Lure and preparation	Test No.	Number of pieces				Total	Percent eaten	Reaction
		Not seen	Ig-nored	Re-jected	Eaten			
Elbow macaroni:	1	-	2	3	3	8	62	X
	3	-	3	4	1	8	12	X
plus aluminum and	5	-	4	3	1	8	12	X
extract	7	-	2	6	-	8	0	X
	9	-	4	4	-	8	0	X
	11	-	6	2	-	8	0	X
Totals		-	21	22	5	48	10	
Agar strips:	2	-	-	-	8	8	100	XX
	4	-	-	-	8	8	100	X
plus aluminum and	6	-	-	-	8	8	100	X
extract	8	(1)	-	-	7	7	100	X
	10	-	-	-	8	8	100	X
	12	(2)	-	-	6	6	100	X
Totals		(3)	-	-	45	45	100	

Discussion

The pond tests showed that tunny held in captivity would eat edible preparations such as gelatin capsules, pieces of macaroni, and strips of agar gelatin, and that these were more avidly consumed if they were made chemically attractive, or palatable, with concentrated extracts of skipjack or anchovy. In some cases, the relative number eaten seemed to depend, in addition, on the visual attractiveness of the lures.

The pond fish showed a distinct preference to agar preparations over macaroni preparations after the first pair of trials: a learning process seemed to be involved. The reason for the preference is uncertain, but it probably involved a difference in smell, taste, or texture of the materials. Although the two preparations were basically different in composition (macaroni is a starch and agar is a sulphuric acid ester of galactan), both were thoroughly impregnated with the same concentrated extract of skipjack flesh, and presumably should have had a similar smell or taste. Perhaps the considerable difference in texture between the macaroni and agar preparations was responsible for the choice: the strips of agar were softer, more pliable, and more "jelly-like" than the pieces of macaroni.

Although there was no assurance that sea fish would respond in a similar manner to the pond fish (which were accustomed to feeding on dead, non-motile food), it was considered worthwhile to conduct sea tests with edible lures. Unfortunately, attempts to induce appreciable motility in edible lures have been unsuccessful to date. As will be discussed later, motility may be an important factor in the successful use of either edible or inedible lures to attract tuna at sea.

SEA TESTS WITH EXTRACTS

Preparation of Material

For the most part the extracts used in the sea tests were prepared in 50-gallon drums by Mr. F. Jermann of Hawaiian Tuna Packers Ltd. The materials are briefly described as follows:

1. (1) Skipjack viscera, ground, steam-cooked, water added, filtered, preserved with 2 percent sodium bisulphite (demijohns - 1/20/53).

(2) Yellowfin flesh, ground, extracted with water, filtered, and preserved with 2 percent sodium bisulphite (Drum No. 1 - 2/18/53).

(3) Yellowfin flesh, as above (Drum No. 2 - 2/24/53).

(4) Yellowfin flesh, as above (Drum No. 3 - 3/4/53).

(5) Skipjack viscera, ground, extracted with water, preserved with 2 percent sodium bisulphite (Drum No. 4 - 3/13/53).

(6) Skipjack viscera, as above (Drum No. 5 - 5/11/53).

(7) Skipjack viscera, ground, steam-cooked, water added, filtered, and preserved with 2 percent sodium bisulphite (Drum No. 6 - 6/20/53).

(8) Slipjack viscera, ground, frozen into 5-pound blocks (various dates).

All materials were tested on the captive tunny in the pond, in some cases both before and after sea tests. The responses in the pond were generally weak and variable due to the unresponsive condition of the two surviving tunny during the late winter and spring of 1953. However, all substances did produce a response in at least one out of several tests (Tester *et al.* 1954).

The extracts in the demijohns and drums were used either as prepared or they were diluted to various strengths on board ship. The frozen material was thawed and extracted with sea water on board ship for at least 1 hour before use.

In addition to the above, two tests were performed with anchovy extract prepared on board by crushing the live bait in buckets of water, allowing the preparation to settle, and then decanting the supernatant liquid.

Methods of Testing

The methods of testing the response of sea fish to the extracts were many and varied. In some cases the extract was poured from buckets from the side or stern of the ship as it described an arc or circle near or around a flock of birds and, presumably, a school of tuna. In the majority of the tests, the tuna school was attracted to the stern with live bait, chumming was stopped, and the extract was poured over the stern into the group of feeding fish. In others, when chumming ceased, the extract was poured in varied quantities and dilutions from the port and/or starboard sides forward of amidships. In still others, it was pumped in a stream or spray from amidships; the pump was controlled from the flying bridge where the fish could be seen.

Results

In all, 16 tests were performed with skipjack or yellowfin extract and 2 with anchovy extract, with several trials per test in some cases. The tests were performed mostly on schools of skipjack or on mixed schools of skipjack and yellowfin, skipjack and tunny, or skipjack and frigate mackerel. In addition two tests were conducted on a pure school of frigate mackerel and one on a school of dolphin.

The results were either negative or inconclusive. Unchummed schools could not be raised by an arc or circle of extract. Chummed schools could not be held at the stern by introducing the extract in small quantities by either bucket or pump.

In a few tests, on pouring in a large quantity of extract after the school had been chummed to the stern and chumming was stopped, a few fish were seen jumping in or passing through the material. It could not be determined whether they were responding to the extract or were chasing stray baitfish. The latter seems to be the more likely explanation.

Discussion

In view of the results outlined above, and others to be reported below in which extracts were used in combination with edible lures, it may be concluded with reasonable certainty that the local skipjack will not respond to extracts of skipjack viscera, yellowfin flesh, and anchovy. It seems likely that this conclusion also applies to local tunny and yellowfin, which showed a response in the pond but not at sea. However, the sea tests on tunny and yellowfin were few in number and were conducted on schools in which they were mixed with skipjack. There is the possibility that they might respond to the extracts if schooled alone.

No sea tests were conducted with extracts of squid and shrimp, both of which might be considered to be a more natural food than skipjack, yellowfin, or anchovy, and therefore might be expected to elicit a response even though the other materials failed. There were several reasons for not using extracts of squid and shrimp, including the lesser availability and higher cost of these materials. The chief reason was that the pond fish had responded well to tuna flesh extracts even though they had been fed exclusively on squid for a period of 2 months. This indicated that they had not been conditioned to any particular food item, but rather were responding to an "attractant" which was generally distributed throughout all food items. It was assumed that this might also be the case with the fish in their natural environment, and that if they responded at all, they would respond (almost) equally well to extracts of tuna, anchovy, shrimp, squid, etc.

The negative results obtained in the sea tests indicate that the sense of smell plays little or no part in the feeding of skipjack, and perhaps other species of tuna as well, in their natural environment. They further indicate that the pond fish had learned to associate the smell of the juices of cut-up food material with the act of feeding and thus exhibited a conditioned response to the extracts, as already discussed in a previous section.

SEA TESTS WITH INEDIBLE LURES

Attention was next directed at a study of the response of tuna at sea to objects which might be visually attractive and which could perhaps be used as chum either alone, with extracts, or with live bait.

Materials

The following materials were prepared and tested (others were prepared, but there was either no opportunity for testing them or it was obvious that no further information would be obtained by testing them):

(1) aluminum foil: 3/8-inch squares; used dry (floating) or wet with water and Tergitol (slowly sinking).

(2) tin strips: approximately 1/4 x 2 inches; cut from tin cans (one test) or tin plate (several tests).

(3) tin trangles: approximately 2 inches across, with concave sides (cut from tin plate from which can tops had been stamped out).

(4) mica flakes: "artificial snow".

(5) calcium carbide pellets: approximately 1/4- to 1/2-inch pieces of irregular shape.

Three "drag lure arrays" were prepared and used: (1) an 8-foot iron bar to which were attached small strips of tin with wire leaders; (2) a 10-foot iron bar, V-shaped, to which were attached tin strips, highly polished sport-fishing spoons with hooks, or rubber fish with or without hooks; (3) two 8-foot 1/2-inch pipes connected at one end to a "T" and bent into a V-shape, to which were attached leaders and lures of various kinds. Extracts could be supplied to this last array through a 1/2-inch garden hose (75 feet long) connected to the "T". The extract was dispersed through holes drilled in the arms of the V-shaped pipe.

Methods of Testing

In all tests with inedible objects, the fish were first chummed to the stern with live bait, chumming was stopped, and the materials were thrown to the feeding fish and the response noted. In later experiments a quantitative measure of response was employed: (a) the fish were chummed to the stern, a few were caught by the fishermen, and chumming was stopped although the fishermen continued fishing--the time (in seconds) from the cessation of chumming to the disappearance of the fish was recorded, as well as the number of fish caught during this period; (b) the school was then re-chummed to the stern with live bait, a few were caught, chumming with live bait was stopped and chumming with the objects was started--again, the time to the disappearance of the fish and the number of fish caught during this period were recorded.

In several experiments extracts were introduced at the same time as the inedible lures were presented to the fish.

The drag lure arrays were towed behind the ship at various distances (up to about 75 feet) both in chasing a school without using chum and also after having chummed a school to the stern. In some experiments extracts were released either from the stern or side of the ship, or in the case of the third drag lure, through the garden hose by siphoning action.

Results .

Some 40 experiments were conducted with inedible objects and drag lures, including those with and without the use of extract. Typical results for some of those in which the response was measured are included in table 5.

There was no noticeable response to the strips of red cellophane or the mica flakes. The squares of aluminum foil produced a momentary attraction to the chummed fish, but would not hold them.

The tin strips and triangles, which gyrated and flashed in the water as they sank, were temporarily attractive to the fish. When a school was chummed to the stern with live bait, individual tuna could be momentarily lured from the stern to amidships by chumming with strips or triangles of tin from the latter location. This was repeated on several occasions. However, having investigated the flashing tin, the skipjack would return to the stern to feed on live bait. Of 57 skipjack caught from one school during such experiments, 2 had one strip of tin apiece in the stomach. In some tests, when chumming with live bait was replaced by chumming with tin strips from the stern, the fish remained with the ship for a slightly longer period than when no chum was used, but they followed the strips of tin as they sank and therefore kept beyond the reach of the poles.

The calcium carbide pellets gave off bubbles of acetylene gas when thrown into the water, along with a milky precipitate which streamed behind the pellets as they sank. This visual stimulus seemed to attract the fish and hold them for a short period of time. However, no pellets were found in the stomachs of fish which were caught, and no dead or distressed fish were noted in the fishing area after chumming with this active chemical.

The addition of extracts when chumming with visual lures did not seem to cause any added excitement or attraction.

The lure array, either without or with the addition of extract, did not seem to attract the schools when towed near them. However, it was difficult to keep up with the schools when the array was being towed; usually the schools managed to keep ahead of the ship. As shown by data included in table 5, towing the lure array close to the stern after the fish had been chummed with live bait did not seem to hold them for any additional period of time beyond that of the controls.

Discussion

Obviously little success was achieved in attracting and holding schools of tuna with inedible lures of the types which were used. The observation that the tuna will respond to some extent to shiny objects such as strips of tin, silvery objects such as squares of aluminum foil, and effervescing objects such as wet calcium carbide pellets is of interest and possible value in devising other artificial lures. The results suggest that the sense of vision is of major importance in the feeding of tuna in their natural environment.

SEA TESTS WITH EDIBLE LURES

Materials

The preparation of edible lures, consisting basically of gelatin capsules, macaroni, and agar, has been described in a previous section. There was no opportunity of testing the gelatin capsules at sea. Several tests were performed with the non-motile, edible, macaroni and agar preparations. In addition experiments were performed with dead anchovy, cut-up preserved herring, and strips of skipjack flesh, both without and with the addition of extract.

Methods of Testing

In one series of experiments with macaroni and agar preparations the method of testing was similar to that finally adopted with inedible lures, namely, to establish a control time (to disappearance of fish) and count (of fish caught) after chumming with live bait ceased, and to determine a test time and count while chumming the previously live bait-chummed fish with the edible lure. In a second series of experiments direct chumming of the schools with edible lures was attempted. When possible, this was followed by chumming with live bait to see if the school would respond.

With the other experiments (dead anchovy, herring, etc.) the materials were used as chum in some cases after the tuna had been chummed to the stern with live bait and in others without chumming with live bait.

Results

The results of the first series of experiments with macaroni and agar preparations are included in table 5. On comparing the timing and catch under control and test conditions, there is no indication that the edible lures were attractive to the fish.

The second series of experiments, involving direct chumming with the edible lures, was undertaken following a suggestion that the skipjack might be temporarily conditioned to feeding on live bait and, for that reason, might not feed on the edible lures when they were subsequently presented.

Attempts were made to chum ten different schools with edible lures during October and November 1953 with negative or inconclusive results. While attempting to chum three skipjack schools and one dolphin school with macaroni and agar preparations, fish were caught on the trolling jigs soon after chumming began, but there was no assurance that this was related to the chumming. In all other cases except one, the results were negative. For the most part, the schools were "wild". Of nine tuna schools, one was chummed to the stern of the vessel with difficulty using live bait, two failed to respond to live bait, two disappeared before live bait could be used, and for the remaining four, no live bait was available.

The one exception might be described in more detail. A large school of 17- to 25-pound skipjack was chummed in five different passes with one or a combination of the following edible lures: macaroni cooked in skipjack extract and coated with aluminum, macaroni cooked in skipjack extract but uncoated, macaroni cooked in water and coated with aluminum, agar cooked in skipjack extract and impregnated with aluminum, macaroni cooked in anchovy extract and coated with aluminum, and cubes (3/4-inch) of skipjack flesh. On each pass the skipjack were attracted to the stern and, in all, 67 of them were caught with pole and jig. Live bait was not used; none was available. However, it was suspected that the school of skipjack was feeding on opelu (Decapterus) and that each time the vessel approached the school the opelu sought refuge under it, thus attracting the skipjack to within reach of the poles. Opelu were spat up by some of the fish which were caught, and were also found in the stomachs. Moreover, some of the fishermen reported having seen the opelu in the water. None of the stomachs which were examined contained edible lures.

In earlier experiments, after skipjack had been chummed to the stern with anchovy, chumming was stopped, and dead anchovy were thrown to the feeding fish. They exhibited continued feeding activity for a time, but followed the dead fish down as they sank. Attempts to chum skipjack schools with strips of skipjack flesh failed. The strips were cut to include the silvery skin on one side, and were about the same size as the anchovy used as chum.

Table 5.--Time (in seconds) and catch (in numbers of fish) during control and test conditions when testing inedible lures, lure arrays, and edible lures (for explanation see text)

Experiment No.	Lure	Control		Test	
		Time	Catch	Time	Catch
S52	Mica flakes	30	2	30	0
S53	Mica flakes plus extract	18	0	15	0
S54	Tin strips	43	4	75	0
S56	Tin strips	-	-	190	0
S49	Calcium carbide	20	0	60	0
S50	Calcium carbide plus extract	25	0	115	2
S57	Lure array (3) with spoons	20	0	20	0
S58	Lure array (3) with spoons and extract	25	1	30	0
		-	-	35	0
S59	Lure array (3) with rubber fish	45	2	36	0
S60	Macaroni plus extract plus aluminum, plugged with cotton	100	14	110	7
S61	Macaroni plus extract plus aluminum	45	5	40	1
		-	-	43	4
S62	Agar strips plus extract plus aluminum	30	1	30	0
		-	-	45	1

Discussion

Failure to attract and hold the schools of tuna with non-motile edible lures perhaps was to be expected in view of the fact that present fishing methods (for skipjack) depend on the use of live rather than dead bait. However, in view of the success in pond tests, it was hoped that the fish at sea would respond, to some extent at least, to the extract-impregnated lures. This hope was not realized. Possibly some response of interest might be noted if the experiments with direct chumming (without the preliminary use of live bait) were repeated under more favorable circumstances, e.g., during the regular summer fishing season when skipjack schools are plentiful and when they respond well to live bait.

There is the possibility that tuna in other parts of the world, particularly those species which will take dead bait on longline gear, might respond to the macaroni or agar preparations. Dr. W. M. Chapman, Director of Research of the American Tunaboat Association, has informed us (verbally) that in the California fishery yellowfin have responded to plain cooked macaroni on occasion. With fish such as these, a positive and consistent response might be obtained if the extract-impregnated, silver-colored macaroni or agar preparations were used.

SUMMARY AND APPRAISAL OF RESULTS

The main object of this investigation has been to study the response of tuna to chemical and visual stimuli in the hope that the information so gained can be utilized in developing a substitute for live bait.

In the past 2 years numerous experiments have been conducted on the response of captive little tunny to chemical stimuli. A screening of over 100 known chemical compounds ranging from simple inorganic to complex organic materials and including several reputed fish attractants has been undertaken. Apart from an apparent sensing of some of the strong-smelling aromatics and an avoidance of some of the highly-colored dyes, the results have been negative. It seems unlikely that further screening of chemicals will produce any worthwhile information.

It has been found that the captive tunny respond with a vigorous feeding reaction to extracts of "food" substances such as skipjack and other fish (flesh, viscera, blood), squid, and shrimp. The response to these several substances was obtained regardless of which one was being fed to the fish as a subsistence diet. However, there was an indication of a slightly better response to a particular extract when the substance from which it was prepared was being used as food. This observation, together with the fact that the fish were being fed on dead, cut-up materials, suggested that the captive fish may have learned to associate the smell of the juices exuding from the cut-up food with the act of feeding and that the response to extracts was entirely conditioned by the nature of the food. This would presume that the so-called "attractant" in the extracts is a substance (or substances) common to the body juices of fish, squid, shrimp, and other forms. As the captive tunny will not forage for live bait occurring in the pond, but rather must be hand-fed, it is unlikely that further information on the question of conditioning can be obtained from pond experiments.

It was hoped that even if there was a partial conditioning of the pond fish, tuna in their natural environment might be naturally "conditioned" to associate the smell of living injured or uninjured prey with the act of feeding, and that they would therefore respond to the extracts. This hope was not realized. A sufficient number of sea tests on skipjack schools were conducted to warrant the conclusion that the fish showed no appreciable response to extracts of skipjack flesh and viscera, extracts of yellowfin flesh, and extracts of live bait. Unfortunately no tests were conducted on "pure" schools of little tunny (the species tested in the pond) or yellowfin (which are known not only to eat dead bait on longlines but to respond occasionally to chumming with cut bait). Also, no sea tests were conducted with extracts of squid and shrimp, both of which might be considered a more natural food than skipjack or yellowfin flesh. Nevertheless the negative results obtained from such sea tests as have been conducted indicate that the sense of smell plays little part in the feeding of tuna in their natural environment.

A study was made of the response of tuna at sea to a variety of inedible lures which were used as chum, both with and without extract, after the fish had been initially chummed to the stern of the ship with live bait. There was a momentary response to shiny objects such as strips of tin, to silvery objects such as squares of aluminum foil, and to effervescing objects such as calcium carbide pellets. Similarly there was a momentary response to dead baitfish. The addition of extract had no apparent effect. These results indicate that the sense of vision plays a much greater role in feeding than the sense of smell. However, neither these visual lures nor a "drag-lure array" (designed to simulate a school of live bait) towed behind the vessel was successful in holding the fish at the stern.

The captive tunny in the pond were used to test a variety of edible lures in which the qualities of visual attractiveness and palatability were combined. Gelatin capsules, pieces of macaroni, and strips of agar treated with concentrated extract were eaten more frequently than when they were not treated with extract. In some of the edible lures, visual attractiveness was increased by coating or impregnating with aluminum powder. In a series of experiments in which the captive tuna were presented alternately with macaroni pieces and agar strips, both cooked in concentrated extract and made silvery with aluminum, the fish showed a preference for the agar. The preference may have been associated with the texture of the material. It became more pronounced with successive testing, suggesting that a learning process was involved.

Sea tests with these edible lures gave negative or inconclusive results. Unfortunately the tests were made during the autumn, when skipjack schools were both scarce and erratic in their behavior. Several of the schools which failed to respond to the edible lures also failed to respond to live bait. The experiments with the more promising substances (particularly with agar strips impregnated with concentrated extract and aluminum powder) should be repeated during the regular summer skipjack season. If they again fail to attract our local skipjack schools, which are notoriously difficult to chum with live bait, it does not necessarily follow that they will also fail to attract skipjack, yellowfin, or other tuna species elsewhere.

In view of the lack of success in attracting local skipjack schools to the stern of a vessel and holding them there with the many materials and combinations of materials which have been used, we may ask what quality of attraction is missing. The missing quality is probably motion--the rapid motion of a living fish or squid, or the rapid motion of a lure trolled through the water. It may be that motion is a prerequisite to attraction by artificial lures. Other qualities of likely importance are size, shape, appearance, texture, and taste of the lures.

Imparting motion to a small object (say, 2 to 4 inches in length and 1/2 to 1 inch in diameter) is a difficult although not impossible task. One method is to use the energy of a chemical reaction and the principle of jet propulsion. Once a satisfactory "motor" has been devised, other problems concerning buoyancy, shape, speed, nature and direction of movement, and fabrication of a self-propelled lure may be tackled. In fabrication the problem of cost looms large, but may be dismissed pending the development of successful experimental models. The problem of making the lure attractive in appearance, texture, and taste does not seem to offer such formidable difficulties as that of imparting motion.

An investigation of methods of imparting motion to small objects is presently underway. If a promising motile lure can be devised, it will be tested on schools of skipjack at sea.

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APPENDIX

A summary of experiments conducted in tank (T) and pond (P) by Tester (ALT) or Takata (MT), with reaction classified as positive (X to XXX), no response (0), or negative (-), over the period July to September 1953. All experiments, except one, conducted on little tunny.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
357	7/1	Skipjack viscera, 250 ml. (50 lb. extracted with water, heated, filtered, and decanted --HTP--6/20/53).	P	ALT/MT	0	No indication of attraction--yellowfin only timed and counted.
358	7/1	Skipjack viscera, 500 ml. (Same as #357).	P	ALT/MT	0	Possibly a slight attraction, but not certain.
359	7/1	Skipjack flesh, 1,000 ml. (250 g. extracted with 2,250 ml. water--whole extract--7/1/53).	P	ALT/MT	XX	Speeding and feeding; jacks also reacted.
360	7/1	Skipjack flesh, 1,250 ml. (Same as #359).	P	ALT/MT	XXX	Very good reaction.
361	7/2	Skipjack flesh, 500 ml. stock extract. (equivalent to about 50 g. flesh).	P	ALT/MT	X	Mostly speeding.
362	7/2	Skipjack viscera, 500 ml. (Same as #357).	P	ALT/MT	X	Slight speeding and slight feeding.
363	7/2	Skipjack viscera, 500 ml. (Same as #357).	P	ALT/MT	0	No noticeable reaction.
364	7/2	Skipjack flesh, 1,000 ml. stock extract. (equivalent to about 100 g. flesh).	P	ALT/MT	X	Slight speeding and turning back; yellowfin also reacted slightly.
365	7/2	Anisic aldehyde C. P., 8 ml.	P	ALT/MT	0	Slight speeding in 1st and 2nd periods, but whether or not it was due to material is uncertain.
366	7/6	Skipjack flesh (100 g. extracted with 3 liters water for 3 hours--whole extract).	P	ALT/MT	X	Mostly speeding with little feeding.
367	7/6	Skipjack flesh, 1 liter stock extract.	P	ALT/MT	0	Possibly a slight reaction in 1st period, but not certain--pump turned off except for introducing material.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
368	7/6	Skipjack viscera (100 g. extracted with 3 liters water--whole extract--7/2/53)	P	ALT/MT	O	Possibly sensing in 1st period, but no noticeable reaction.
369	7/7	Skipjack flesh (265 g. extracted with 4 liters water overnight--filtrate).	P	ALT/MT	X	Slight reaction with speeding; jacks also reacted slightly.
370	7/7	Squid (180 g. extracted with 3 liters water overnight--filtrate).	P	ALT/MT	XX	Speeding and feeding by tunny and yellowfin.
371	7/7	Citral, 10 ml.	P	ALT/MT	O	No indication of sensing.
372	7/7	Amyl cinnamate, 10 ml.	P	ALT/MT	O	
373	7/8	Hammerhead shark flesh (130 g. extracted with 1,500 ml. water overnight--filtrate).	P	MT	O	Jacks reacted slightly in 2nd period.
374	7/8	Shrimp, 1 liter (250 g. extracted with 2 liters water overnight--filtrate).	P	MT	XX	Definite reaction with feeding.
375	7/8	Shrimp, Same as #374	P	MT	XX	Good feeding reaction; yellowfin and jacks also reacted.
376	7/8	Squid, 1,500 ml. (135 g. extracted with 2 liters water overnight--filtrate).	P	MT	X	Mostly speeding; yellowfin reacted with tunny and independently; jacks also reacted slightly.
377	7/9	Dolphin ovary (177 g. extracted with 2,800 ml. water overnight--whole extract).	P	MT	X	Slight reaction with speeding.
378	7/10	Skipjack flesh, 500 ml. stock extract.	T	ALT/MT	XXX	Good reaction with speeding, turning, and feeding.
379	7/10	Skipjack flesh, 1 liter stock extract.	P	ALT/MT	X	Speeding with some feeding.
380	7/10	Squid, 500 ml. (135 g. extracted with 2 liters water--filtrate--7/7/53).	T	ALT/MT	XXX	Violent reaction, much more so than #378; there was much splashing and feeding.
381	7/10	Squid (100 g. extracted with 1,500 ml. water--filtrate--7/7/53).	P	ALT/MT	X	Much speeding, little feeding, and little turning.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
382	7/10	Shrimp (50 g. extracted with 500 ml. water--centrifuged immediately--centrifugate cloudy).	T	ALT/MT	X	Sensing and speeding.
383	7/13	Skipjack blood (130 ml. diluted to 1,000 ml. with salt water--7/10/53).	P	ALT	X	Mostly sensing and speeding but with some returning and swirling; yellowfin reacted with tunny.
384	7/14	Anchovy, 1,000 ml. (120 g. extracted with 1,500 ml. water overnight--whole extract).	P	ALT	X	Very slight but positive reaction; yellowfin and jacks also reacted slightly.
385	7/14	Anchovy, 500 ml. (Same as #384).	T	ALT	X	Slight reaction only at beginning.
386	7/14	Shrimp (50 g. extracted with 900 ml. water filtrate).	T	ALT	X	Slight excitement with feeding reaction.
387	7/14	Plankton (35 g. extracted with 600 ml. water--plankton was collected outside Kaneohe Bay).	P	ALT	X	Sensing with some swirling and turning back.
388	7/14	Squid (67 g. extracted with 1,000 ml. water overnight--whole extract).	P	ALT	XXX	Great excitement, feeding and turning back.
389	7/14	Skipjack flesh, 500 ml. stock extract 7/9/53.	T	ALT	XX	Good reaction with swirling and feeding.
390	7/15	Methionine, 0.5 g.	P	ALT	0	Fish remained deep.
391	7/15	Skipjack flesh, 1,000 ml. stock extract--7/9/53.	P	ALT	XX	Speeding, surfacing; some returning, but no feeding; yellowfin reacted with tunny and also independently.
392	7/15	Hammerhead shark flesh (90 g. extracted with 500 ml. water --whole extract--7/13/53).	T	ALT	0	Slight speeding when they sensed the material but no reaction thereafter; no timing.
393	7/16	Hammerhead shark flesh (150 g. extracted with water--filtrate--7/15/53).	P	ALT	XX	Tunny, yellowfin, and jacks reacted in first 3 periods. This was a good reaction compared with former results obtained with this material.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
394	7/16	Skipjack flesh, 1,000 ml. stock extract--7/9/53.	P	ALT	X	Tunny and yellowfin reacted slightly.
395	7/16	Eucalyptol--U.S.P., 6 ml.	P	ALT	0	
396	7/16	Anchovy (100 g. extracted with 1,000 ml. water--whole extract--7/13/53).	P	ALT	0	Practically no reaction; could the eucalyptol tested just prior to this test be responsible?
397	7/16	Squid (100 g. extracted with 1,000 ml. water--whole extract--7/13/53).	P	ALT	X	Weak reaction by tunny and yellowfin
398	7/21	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	X	Tunny and yellowfin acted together and independently; fish were still excited and milling after the test.
399	7/21	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	XX	Better reaction than #398; yellowfin reacted in 9th period.
400	7/21	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	X	Very slight reaction by tunny and jacks at first, but it didn't last.
401	7/21	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	XXX	Excellent reaction by tunny, yellowfin, and jacks in first 5 periods.
402	7/22	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract--material smelt bad).	P	ALT	XX	Tunny reacted immediately and yellowfin later; no feeding observed but turning, swirling and speeding for both.
403	7/22	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract)--smelly?	P	ALT	X	Sensing by tunny in 1st period; slight excitement by yellowfin which didn't last.
404	7/22	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract)--smelly.	P	ALT	X	Definite speeding with some attraction for both tunny and yellowfin.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
405	7/22	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	XXX	Strong reaction with great excitement and swirling; yellowfin reacted slowly.
406	7/23	Blend of squid, skipjack and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	XX	Very good initial reaction by both tunny and yellowfin.
407	7/23	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	X	Slight reaction by tunny and yellowfin
408	7/23	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	XXX	Excellent reaction with swirling, returning and feeding; yellowfin and jacks reacted with tunny in 7th period.
409	7/23	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT	0	Practically no excitement--a slight swerving only at first.
410	7/27	Isoeugenol, 10 ml.	P	MT	0	
411	7/27	Magna spice concentrated bologna flavor, 10 ml.	P	MT	0	
412	7/27	Blend of squid, skipjack and shrimp (1,000 ml. stock solution--100 g. equiv. with 2% sodium bisulphite--kept at room temperature).	P	MT	XX	Speeding with some feeding by both tunny and yellowfin.
413	7/27	Imitation butter flavor, alcohol soluble, 10 ml.	P	MT	0	Slight repellent effect in 1st period? Slight feeding by tunny and yellowfin on what seemed to be oil in material which floated on surface.
414	7/28	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	X	Slight reaction with circling and returning.
415	7/28	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	XX	Definite reaction in 1st and 2nd periods by tunny and yellowfin with slight speeding.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
416	7/28	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Both tunny and yellowfin reacted in first 3 periods, but no noticeable reaction thereafter.
417	7/28	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract--added 2% sodium bisulphite).	P	MT	X	Erratic behavior.
418	7/29	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slight reaction with turning and speeding; yellowfin sensed material but did not react; jacks reacted in 1st period.
419	7/29	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Good reaction with turning, swirling, dashing, surfacing and feeding; one yellowfin reacted slightly.
420	7/29	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Weak but definite reaction with slight feeding in 1st period only.
421	7/29	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slow reaction--no noticeable speeding; good reaction with feeding by yellowfin.
422	7/30	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	0	Slight sensing and slight speeding in 2nd period only.
423	7/30	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Weak reaction with some feeding, turning, and speeding; yellowfin sensed material but did not react.
424	7/30	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slight reaction with some turning and speeding 1st period only.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
425	7/30	Blend of squid, skipjack and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Good reaction with turning, surfacing and feeding; yellowfin and jacks sensed material but did not react.
426	7/31	D L Asparagine, 2 g.	P	MT	0	
427	7/31	Anethol, 5 ml.	P	MT	0	
428	7/31	L Arginine monohydrochloride, 2 g.	P	MT	0	
429	7/31	D L Serine, 3 g.	P	MT	0	
430	7/31	D L Leucine, 2 g.	P	MT	0	
431	8/3	Alpha keto glutaric acid, 3 g.	P	MT	0	
432	8/3	D L Histidine monohydrochloride, 2 g.	P	MT	0	
433	8/3	L Hydroxyproline, 1 g.	P	MT	0	
434	8/3	L Tryptophane, 1 g.	P	MT	0	
435	8/3	Guanine, 2 g.	P	MT	0	
436	8/4	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Weak reaction with some returning but no feeding.
437	8/4	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Good reaction with returning, surfacing and feeding in 1st period only; sensing but no reaction by jacks.
438	8/4	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Reaction in 1st period only, but speeding through 5th period; slight speeding by yellowfin.
439	8/4	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract)--smelt bad.	P	MT	X	Very weak reaction in 1st period only.
440	8/5	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XXX	Very good reaction with turning, surfacing, and feeding initially but did not last.

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
441	8/5	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	XX	Good reaction in 1st period only.
442	8/5	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slight reaction with some feeding by 2 tunny early in 1st period.
443	8/5	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slight reaction in 1st period only; fish confined most of their activities to shallow water.
444	8/6	Squid (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	X	Speeding and returning but no feeding.
445	8/6	Skipjack flesh (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	X	Slight reaction in 2nd period and slight feeding in 3rd period.
446	8/6	Shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	0	Slight sensing in 1st period only.
447	8/6	Blend of squid, skipjack, and shrimp (100 g. extracted with 2,000 ml. water overnight--whole extract).	P	ALT/MT	0	No noticeable reaction at any time--merely a slight speeding.
448	8/7	Histidine (free base), 2 g.	P	MT	0	Fish swimming deep.
449	8/7	Sodium bisulphite, 2 g.	P	MT	0	
450	8/7	D L Alpha alanine, 2 g.	P	MT	0	
451	8/7	L Lysine monohydrochloride, 2 g.	P	MT	0	
452	8/7	D L Glutamic acid monohydrate, 1 g.	P	MT	0	
453	8/7	L Aspartic acid, 2 g.	P	MT	0	Most of the tunny did not come within the influence of the material during the early periods.
454	8/10	Glycyl-glycine, 1 g.	P	MT	0	
455	8/10	Alpha amino n butyric acid, 2 g.	P	MT	0	
456	8/10	D L Norvaline, 1 g.	P	MT	0	
457	8/10	Xanthophyll oil, 10 ml.	P	MT	0	

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
458	8/10	D L Trypotophane, 1 g.	P	MT	0	
459	8/10	Chlorophyll, 2 g.	P	MT	-	Repellent effect, especially during first 2 periods.
460	8/11	D L Thronine (with allothreonine), 2 g.	P	MT	0	
461	8/11	D L Threonine, 1 g.	P	MT	0	
462	8/11	Pyridoxine hydrochloride, 1 g.	P	MT	0	
463	8/11	D L Aspartic acid, 2 g.	P	MT	0	
464	8/11	Guanine hydrochloride, 1 g.	P	MT	0	
465	8/11	Uramil, 2 g.	P	MT	0	
466	8/12	D L Lysine monohydrochloride, 2 g.	P	MT	0	Tunny remained at south end of pond for the first 5 periods.
467	8/12	L Proline, 1 g.	P	MT	0	
468	8/12	D L Ornithine monohydrochloride, 1 g.	P	MT	0	
469	8/14	Skipjack flesh (100 g. pale flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	0	No noticeable response.
470	8/14	Skipjack flesh (100 g. dark flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	XX	Good reaction with speeding.
471	8/17	Skipjack flesh (100 g. extracted with 2,000 ml. water--whole extract--8/14/53).	P	MT	X	Very slight reaction.
472	8/18	Skipjack flesh (100 g. dark flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	X	Mostly speeding which lasted through the 5th period; violent reaction and feeding by Abudefduf.
473	8/18	Skipjack flesh (100 g. pale flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	XX	Good reaction with much speeding and little feeding.
474	8/18	Betaine, 5 g.	P	MT	0	

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
475	8/18	Skipjack flesh, 100 g. equiv. (600 g. extracted with 2,100 ml. 95% ethyl alcohol and centrifuged; residue extracted again with 1,000 ml. alcohol; centrifugate evaporated to a viscous mass by heating; and concentrate redissolved in water).	P	MT	X	Some turning back and much speeding--speeding lasted throughout experiment.
476	8/18	Skipjack flesh, 200 g. equiv. (same as #475).	P	MT	0	Very slight speeding up.
477	8/19	Skipjack flesh, 100 g. equiv. (same as #475)	P	MT	0	Slight sensing in 1st period only.
478	8/19	Skipjack flesh (100 g. pale flesh extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slow reaction--no speeding.
479	8/19	Skipjack flesh, 200 g. equiv. (same as #475)	P	MT	0	No noticeable reaction.
480	8/19	Skipjack flesh (100 g. dark flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	XX	Good reaction with some feeding.
481	8/20	Skipjack flesh (residue from exp. #475 extracted with water --centrifugate).	P	MT	0	
482	8/21	Skipjack flesh (100 g. dark flesh extracted with 2,000 ml. water overnight--whole extract).	P	MT	X	Slight reaction with some turning and speeding.
483	8/21	Skipjack flesh, 200 g. equiv. (400 g. extracted overnight with 95% ethyl alcohol--centrifugate).	P	MT	0	Possibly slight repellent effect.
484	8/21	Skipjack flesh (100 g. pale flesh extracted with 2,000 ml. water overnight--whole extract)	P	MT	X	Some turning and feeding; this reaction was slightly stronger than that obtained with the dark flesh tested previously (#482).

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
485	8/21	Skipjack flesh, 200 g. equiv. (400 g. extracted overnight with 95% ethyl alcohol, centrifugate evaporated by heating to viscous mass, and concentrate redissolved in water).	P	MT	X	Turning and speeding--speeding lasted throughout experiment.
486	8/21	Skipjack flesh (200 g. extracted overnight with 2,000 ml. water--whole extract).	P	MT	X	Turning and speeding.
487	8/24	Skipjack flesh (200 g. extracted with 400 ml. water--centrifugate--8/21/53).	P	MT	X	Slight reaction, but much speeding.
488	8/24	Skipjack flesh (200 g. extracted with 200 ml. water and 200 ml. 95% ethyl alcohol--centrifugate--8/21/53).	P	MT	0	Slight speeding in 1st period only.
489	8/24	Skipjack flesh (200 g. extracted with 400 ml. 95% ethyl alcohol--centrifugate--8/21/53)	P	MT	0	Slight speeding in first 2 periods but no noticeable reaction.
490	9/1	D L Tyrosine, 2 g.	P	MT	0	
491	9/2	Phenylalanine, 0.5 g.	P	MT	0	
492	9/2	Thiamine hydrochloride, 2 g.	P	MT	0	
493	9/2	Calcium pantothenate (dextrorotatory), 1 g.	P	MT	0	
494	9/3	Uracil, 1 g.	P	MT	0	
495	9/3	Creatinine, 2 g.	P	MT	0	
496	9/4	Cholic acid, 2 g.	P	MT	0	Erratic behavior.
497	9/4	Liver fraction "L", 2 g.	P	MT	0	Material dark brown in color.
498	9/4	Musk ketone, 2 g.	P	MT	0	Sped just after passing through material in 1st period--sensing (?).
499	9/4	Liver extract concentrate 1:20, 2 g.	P	MT	0	Material dark brown in color, but fish did not seem to notice it.
500	9/8	Cadaverine dihydrochloride, 0.5 ml.	P	MT	0	
501	9/8	Testosterone U.S.P., 0.5 g.	P	MT	0	

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
502	9/8	Skipjack flesh, 500 ml. (4,500 g. extracted with 22,500 ml. water in reefer--supernatant--9/2/53).	P	MT	XX	Good reaction in 1st period with turning and speeding--speeding lasted through 8th period.
503	9/8	Musk ambrette, 2 g.	P	MT	0	Reacting to floating leaves; tunny followed leaves as they were blown out of area.
504	9/8	Musk xylol, 2 g.	P	MT	0	
505	9/11	Amyl caproate, 4 ml.	P	MT	0	Fish sped through area on one pass for no apparent reason, but no noticeable reaction to material.
506	9/11	Ionone C - 1, 5 ml.	P	MT	0	
507	9/11	Viosterol (irradiated ergosterol), 10 ml.	P	MT	0	
508	9/11	Alpha methyl ionone, 5 ml.	P	MT	0	
509	9/11	Phenyl ethyl alcohol, 5 ml.	P	MT	0	
510	9/17	Riboflavin--5--phosphate diethanolamine 2 g.	P	MT	-	Definite repellent effect from this dark orange material.
511	9/17	Tonquin musk synth., 1 g.	P	MT	0	
512	9/17	Casein (nutritional Biochemicals Corp.) 5 g.	P	MT	0	
513	9/18	Eucalyptus oil, U.S.P., 70/75, 2 ml.	P	MT	0	
514	9/18	Crystalline Vitamin A (alcohol), 10 mg.	P	MT	0	
515	9/18	"Astrotone" B R, 2 ml.	P	MT	0	
516	9/18	Phenyl ethyl mercaptan, 2 ml.	P	MT	0	
517	9/18	Adenylic acid (muscle), 0.1 g.	P	MT	0	
518	9/18	Hexahydrobenzoic acid, 2 ml.	P	MT	0	
519	9/21	L Glutamic acid hydrochloride, 5 g.	P	MT	0	
520	9/21	Yeast hydrolysate (enzymatic), 5 g.	P	MT	0	

Exp. No.	Date 1953	Substance and preparation	Tank or pond	Observer	Reaction	Remarks
521	9/21	Lactalbumin, 5 g.	P	MT	0	
522	9/21	Casein hydrolysate (enzymatic), 5 g.	P	MT	0	
523	9/21	Blood fibrin, 5 g.	P	MT	0	
524	9/21	Casein (General Biochemicals, Inc.), 5 g.	P	MT	0	
525	9/21	Gluten, 5 g.	P	MT	0	

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TUNA FISHING AT AMERICAN SAMOA, JANUARY-APRIL 1954

By Wilvan G. Van Campen*

BACKGROUND

In 1949 a company known as Island Packers, Inc., headed by Harold Gatty and financed by the Rockefeller interests, installed a small, modern tuna cannery in some former Navy buildings on the north shore of Pago Pago Bay, Tutuila Island, American Samoa. Attempts to supply this cannery with tuna by live-bait fishing and purse seining in Samoan and Fijian waters failed completely, and the plant was never operated except for 2 trial runs of about 3 tons of fish each. In 1952 the Department of the Interior, in the hope that the plant might somehow eventually make a contribution to Samoa's economy, purchased it to prevent its being dismantled and sold abroad. The Government first offered the cannery for lease in October 1952, but there were no bidders at that time. In May 1953 the Commissioner of Customs ruled that fish caught by foreign vessels could be landed and processed in American

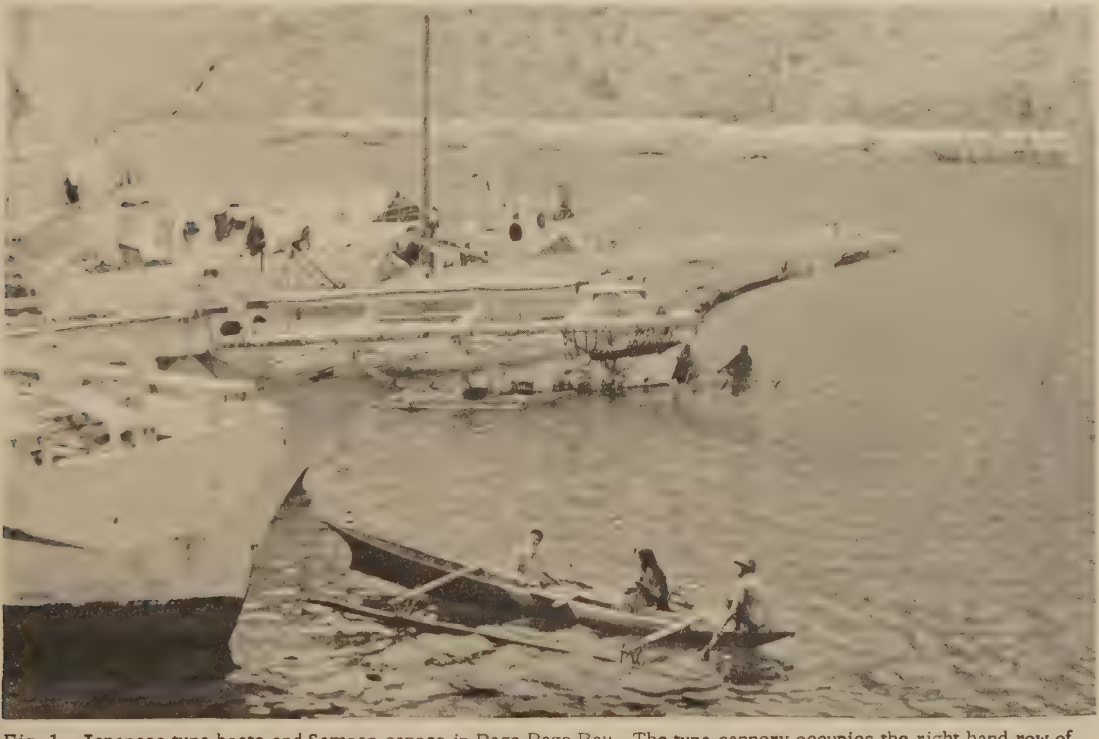

Fig. 1 - Japanese tuna boats and Samoan canoes in Pago Pago Bay. The tuna cannery occupies the right hand row of four buildings on the far side of the bay, with the supervisors' quarters at the extreme right.

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* Translator, Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, Honolulu, T. H.; and scientific observer in Samoa during the first phase of this operation.

Samoa and the product shipped to the United States without payment of United States tariff duties. When a second invitation for bids was issued in July 1953, the Van Camp Sea Food Company, Terminal Island, California, bid for and obtained a 1-year lease with an option to extend for 5 years.

On January 26, 1954, the salmon freezership North Star (1,642 tons gross), chartered by Van Camp from the North Star Fisheries Company of Seattle, rendezvoused at Pago Pago with a fleet of seven Japanese tuna boats, all under contract to a Japanese wholesale and export firm, Tokyo Marine Products, Inc. (Tokyo Suisan Kogyo K. K.). The fleet comprised 3 steel boats of around 150 tons gross and 4 wooden boats of about 100 tons gross. Only one of these was a specialized tuna long liner, the other six being primarily live-bait boats ordinarily engaged in pole-and-line fishing for skipjack and albacore in Japanese waters, and long lining only during the winter as an off-season occupation.

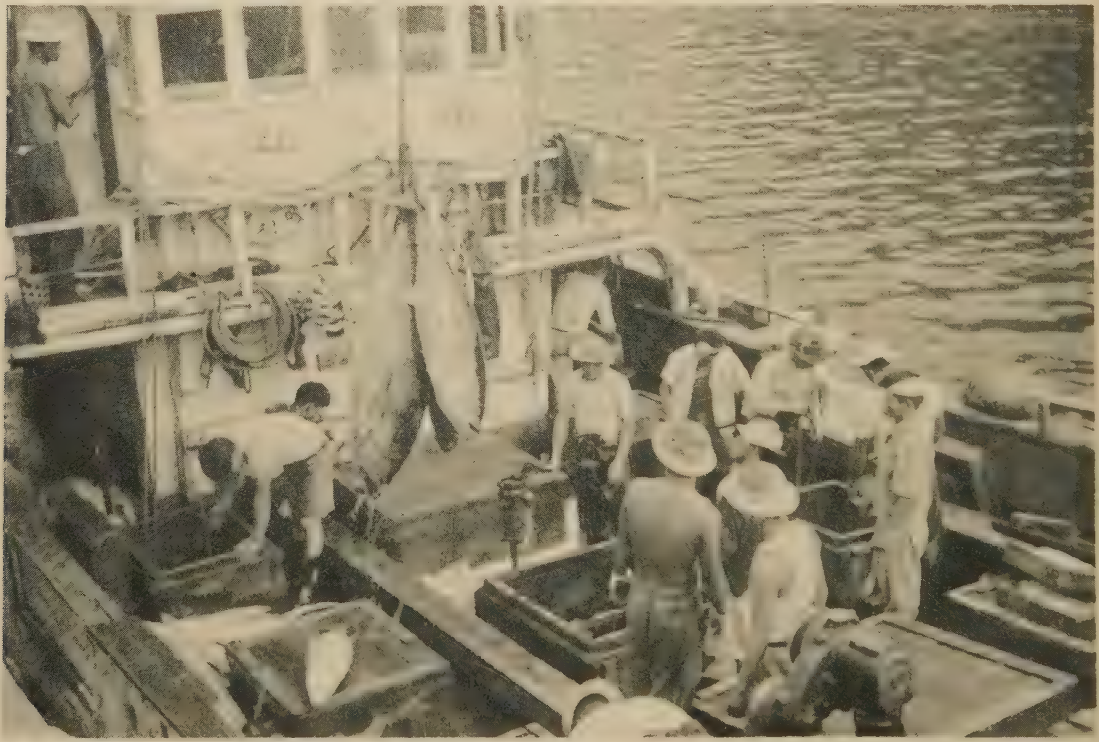

Fig. 2 - Bringing up tuna from the deck of a Japanese fishing boat to the United States freezership North Star, Pago Pago Bay, American Samoa.

The North Star remained in Pago Pago Bay until April 4, supplying the Japanese boats with ice, provisions, and part of their bait and fuel, and freezing the tuna brought in by them. The freezing of fish on the mothership went slowly, especially at first, and it never reached a high level of efficiency. Most of the time, using only 2 of the ship's 6 brine tanks, it took about 24 hours to freeze albacore and about 3 days to freeze large yellowfin.

On March 27 a second United States freezership, the Washington Star (649 tons), under charter to Tokyo Marine Products, arrived in Samoa to take over the duties of mothership, and on April 4 the North Star sailed for San Pedro with about 405 tons of frozen tuna. The fishing boats departed for Japan between March 30 and April 21, except for one with serious engine trouble which did not leave until May 10. The last day on which any fishing was done was April 11. The Washington Star sailed for Japan with a cargo of frozen marlin in the latter part of April.

The cannery was operated from February 8 until March 4, during which period it took mainly very large yellowfin tuna not considered worth exporting to the United States because of the operators' belief that such fish show a high incidence of dark-colored and "green" flesh. The cannery ran again for 3 days early in April, when 3 of the fishing boats brought in fish after the North Star's departure.

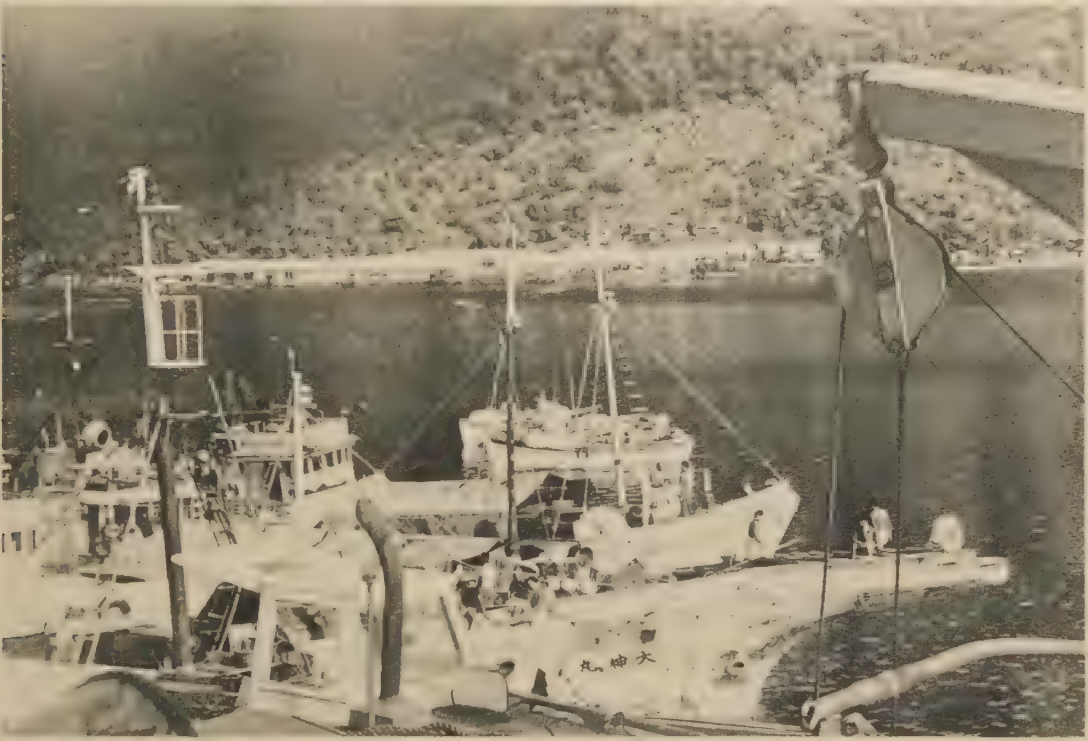

Fig. 3 - Japanese tuna boats alongside the North Star in Pago Pago Bay, with salmon gill-net boats in the middle background and cannery buildings across the bay.

PRODUCTION

The fishing produced a total catch of some 583 tons of tuna; 444 tons of yellowfin, 131 tons of albacore, and $8\frac{1}{2}$ tons of big-eyed and skipjack (table 1). The spearfish catch, which was mostly black marlin, is estimated to have amounted to around 175 tons. Some 50 or 60 tons of this was lost through spoilage, a small quantity was sold locally as fresh fish, and the remainder was frozen aboard the Washington Star for shipment to Japan. Most of the fishing was done in the immediate vicinity of the main Samoan islands: of a total of 198 days of fishing for which positions were reported between January 26 and April 11, 125 days were spent in a 5-degree

Table 1 - Tuna Landings at Pago Pago, American Samoa, by Species and Months, January 27 to April 14, 1954

Species	Month				Totals
	January	February	March	April	
	. . . . (Pounds)				. . . . . .
Yellowfin	136,838	362,483	349,956	38,535	887,812
Albacore	28,920	117,188	85,900	29,821	261,829
Big-eyed	186	6,854	5,882	1,605	14,527
Skipjack	467	1,162	775	-	2,404
Total	166,411	487,687	442,513	69,961	1,166,572

(300-mile) square around the Samoan Islands. Three boats fished briefly in the Tonga area, two cruises were made to the waters north of Fiji, and there was scattered fishing at other locations (table 2). Because of the wide variation in the number of days of fishing in the several areas and the possibility that seasonal changes are involved, it is difficult to compare the areas in terms of abundance of fish. The average catch rates (fish per 100 hooks per day) in table 2 show no clearcut trend in the geographical distribution of the tunas except for the notably higher abundance of albacore in southern Tongan waters.

Table 2 - Number of Days of Fishing and Average Catch Rates (Fish Per 100 Hooks) Reported from Each 5-degree Square (Identified by the Coordinates of the Northeast Corner) from January 26 to April 11, 1954

Square	General Area	No. of Days	No. of Fish/100 Hooks	
			Yellowfin	Albacore
10° S. - 170° W.	Samoa	125	2.02	1.28
15° S. - 170° W.	Northern Tonga	19	1.83	1.94
10° S. - 180°	North of Fiji	15	1.33	2.78
10° S. - 175° W.	West of Samoa	13	1.76	1.31
10° S. - 165° W.	Rose Island and Manu'a	7	1.71	0.83
20° S. - 170° W.	Central and southern Tonga	5	0.63	6.52
15° S. - 175° W.	East of Fiji	4	3.18	1.80
15° S. - 180° W.	Fiji	4	1.20	1.50
00° - 170° W.	Phoenix Island	4	1.83	0.97
00° - 180°	North of Ellice Island	1	1.24	1.31
20° S. - 175° W.	West of Tonga	1	1.93	2.67

Table 3 - Average Catch Rates of All Vessels Reporting by 10-Day Periods

Period	Number of Fish Per 100 Hooks	
	Yellowfin	Albacore
January 20-31	3.62	2.32
February 1-9	2.22	1/3.27
February 10-19	2.37	1.89
February 20-28	2.49	1.46
March 1-9	1.91	1.42
March 10-19	1.69	1.12
March 20-31	1.11	0.80
April 1-9	1.01	1.92
April 10-19	1.15	0.33

1/Includes a few high-catch days of fishing in Tongan waters.

The abundance of both yellowfin and albacore, as reflected in the average catch rates of all vessels by 10-day periods (table 3), was moderately good during the first part of the operation, running around 3 fish per 100 hooks for either species in late January and early February, but this declined progressively until in the latter part of March the rates for both species were down to about 1. At best these catch rates are only mediocre in comparison with rates reported by the Japanese from other parts of the western Pacific, and they are decidedly inferior to the catch rates recorded in the equatorial central Pacific by U. S. Fish and Wildlife Service research vessels.

Table 4 - Average Weight of Yellowfin Tuna in Single Fares

Date Landed	Weight in Pounds	
	Gutted Fish1/	Round Fish
January 27	-	147.8
January 28	-	137.5
February 15	132.7	-
February 24	130.1	-
March 1	114.2	-
March 8	112.8	-
March 12	103.2	-
March 17	109.8	-
March 21	97.7	-
March 26	73.1	-
March 28	112.5	-
March 29	101.8	-

1/All yellowfin and big-eyed were delivered gutted and gilled after the first round of landings.

The apparent decrease in abundance was accompanied by a change in the size composition of the yellowfin catch. The average yellowfin weight dropped steadily from over 130 pounds in the early part of February to around 70 pounds in the latter part of March (table 4). In February, 70 percent of the yellowfin landings were composed of fish over 120 pounds; in April only 24 percent were over that weight (table 5). This decrease in size, of course, lowered the "pay load" per day even more than is suggested by the drop in the numerical catch rates.

Table 5 - Percentages of Yellowfin Tuna over 120 Pounds (Gutted)

Period	Percentage over 120 Pounds
February	70
March 1-14	51
March 15-31	39
April	24

The Japanese fishermen advanced two hypotheses to account for the decline in the apparent abundance of fish: one, that there is a seasonal migration of tuna through Samoan waters, and that the early days of the operation chanced to coincide with this migration; and the other, that the fleet was exploiting a resident population of large fish, "home guards" that had settled down on the shoal areas around Samoa, and that this limited stock was severely depleted during the course of the operation. Only a continuation of fishing over the greater part of a year will show whether either of these notions is correct. It might be noted that in the first part of April, when there were no indications that the fishing had recovered around Samoa, one boat fishing off to the north of Fiji enjoyed fairly good albacore catch rates (3 to 4 fish per 100 hooks).

Sharks, usually an important element in the catch of Japanese tuna long liners, were not brought in by the boats since there was neither storage space nor transportation available for them. They seemed to be generally scarce in the waters fished by this fleet, and available data show shark damage to only about four percent of the tuna on the lines. The catch of tuna species other than yellowfin and albacore and of spearfishes other than black marlin was negligible.

All fishing was done with cotton long lines of standard Japanese design. The gear all had 5-hook baskets, typically with 180 fathoms of main line, a 13-fathom float line, and 12-fathom branch lines. The average number of baskets set per day by each vessel was about 290 and the maximum was 330. Setting was done between 0400 and 0800 hours, at the rate of 1 basket every 45 seconds, and the hauling of the gear took from around 1100 to 2100 hours or later, at the rate of 2 minutes per basket. Crews were 23 to 28 men, except on one of the large steel boats which carried 32.

Counting from the time when they first came alongside the North Star (complete records on the fishing done before that time are not available), six of the boats made four trips apiece and the seventh, which arrived late, made only three. The number of days fished per trip ranged from 3 to 12, the average being $7\frac{1}{2}$. For a total of 203 days of fishing included in this reckoning, the average daily catch was 1.70 tons of yellowfin and .53 ton of albacore.

One vessel fishing in Tongan Waters below 20° S. latitude early in February reported albacore catch rates as high as 8 and 9 fish per 100 hooks, and the albacore from that cruise averaged 50 pounds in weight as compared with an average of about 42 pounds in Samoan waters. Yellowfin were scarce that far south, however, and no further fishing was done there, either because it was more profitable to fish for heavy yellowfin farther north, or because the boats could not obtain the quantities of ice deemed necessary for such long trips.

SMALL BOAT EXPERIMENT

The North Star's complement included four experienced halibut fishermen, who were to make a trial of tuna fishing from 30-foot gasoline-powered motor boats of the type used for fishing salmon gill nets in Bristol Bay. Trolling was given a very brief trial from these boats at first, but with no success at all, and then imported ready-made Japanese long lines were fished, the main lines being reeled in on the hydraulically driven gill-net drums. Hauling by this method was so slow that a boat could operate only about 30 baskets of 4-hook gear per day; that boats were not suitably built nor equipped to work on the open waters of the tropical Pacific; and there were repeated mechanical breakdowns. From January 30 to February 25, when the experiment was abandoned, sporadic fishing by two boats (four men) put a total of 5,756 pounds of tuna aboard the North Star.

LOGISTICS

The major necessities of a Japanese long-liner fleet are ice, frozen bait, rice, and fuel. The motherships North Star and Washington Star undertook to supply the first three, which were practically unobtainable in Samoa, and also as much as possible of the fuel oil, as this was selling at Pago Pago for 14 cents a gallon plus a 3-cent-per-gallon handling charge (later waived under a retroactive agreement). The North Star brought 30,000 gallons of fuel from Seattle for the catcher boats, and when this was used up local supplies were drawn upon.

None of the fishing boats had any mechanical refrigeration, and only one of them, the sole specialized long liner, had any insulation on its fish holds; consequently ice in large quantities was essential to their operations. It is the customary practice of Japanese live-bait boats to leave their fish in the round and hold them in ice water rather than gut them and pack them in crushed ice, as is done on regular long-line boats. This ice water method requires about 1 ton of ice per day for each hold containing fish, and since a Japanese live-bait boat typically has 9 or 12 small fish holds (some of which double as bait tanks), ice consumption is very high. One of these boats will take 50 tons of ice for a 2-week trip. One of the regular long liners, working with a Japanese mothership, would require only about half that much ice. As evidence of this, the one specialized long liner working in Samoa, a 100-ton wooden vessel with three cork-insulated holds, was the only boat in the fleet that brought in a tonnage of fish greater than the tonnage of ice it consumed.

The North Star brought to Samoa 800 tons of ice in 400-pound blocks, which was all that could be loaded into her. A flake-ice machine mounted on the ship worked sporadically at a maximum rate of about 4 tons per day and contributed perhaps 160 tons in all. The 2 tons a day produced by the Samoan Government ice plant, except for the small quantities required for domestic purposes, was brought up and stockpiled by Van Camp Sea Food Company as a reserve supply and amounted to about 75 tons by the time the operation ended. The Washington Star brought from Honolulu 292 tons of ice in 300-pound blocks, arriving just in time to take over the task of icing the catchers for their trip home.

The Washington Star suffered heavy storm damage between the West Coast and Hawaii, and had to spend a whole month undergoing repairs in Honolulu. This made the date of her arrival with the supplementary ice supply uncertain, and measures had to be taken to stretch the obviously inadequate supply in the North Star. These measures took the form of an order to the fishing boat captains to bring in their fish packed in crushed ice rather than in ice water, and a rationing of ice deliveries to the boats at the rate of 30 tons per trip.

Before the arrival of the North Star, the fishing boats that had fish aboard bought small quantities of ice from the government plant at the usual price of $20 a ton (Van Camp was later able to get this price cut in half for its bulk purchases). If this ice is counted in with that brought by the North Star and the flake ice made on the ship, it appears that in round figures nearly 1,000 tons of ice was used to produce less than 600 tons of tuna (leaving marlin out of consideration).

The bulk of the bait for the operation was 25 tons of frozen Japanese saury, shipped to Seattle expressly for this expedition and carried to Samoa aboard the North Star. The mothership also carried 10 tons of American herring, the Washington Star brought another $15\frac{1}{2}$ tons of herring, and the fishing boats brought some saury and a small quantity of sardine from Japan. There was no shortage of bait; indeed, the problem was to find satisfactory storage for it all. The poor catches made by some boats toward the end of the operation were blamed by some fishermen on the deterioration of their bait in storage. Saury was the preferred bait, and practically nothing else was used until the very end of the operation, when some boats that had used up their share of the saury took herring for the trip home.

The North Star carried 30 tons of rice and the Washington Star 10 tons. Both vessels also carried frozen vegetables and cigarettes for the fishing boats. The catchers supplied their own miso, soy, and other Japanese staples, and the fishermen traded fish for local produce, which is limited to such things as taro, breadfruit, bananas, and coconuts. Imported foodstuffs are high-priced and in poor supply at Pago Pago.

Berthing space in Pago Pago Harbor was just barely adequate for the fleet. The freezerships berthed at the Oil Dock and the fishing boats generally berthed at the Customs Pier. These berths are across the bay from the cannery, and all fish sent to the plant had to be trucked about 3 miles around the head of the bay. The cannery has two rather dilapidated small (50 x 22 feet) piers, one of which is being put into condition for use. There are no facilities capable of drydocking a tuna boat anywhere closer than Fiji. The docks at Suva are said to be quite adequate and the service reasonably inexpensive, but there is a great demand for the facilities and dock time must be reserved well in advance; in addition there are, of course, some formalities and attendant delays in the case of a foreign vessel. The government shops in Pago Pago are equipped to handle minor repair jobs, but major breakdowns can be taken care of only with difficulty.

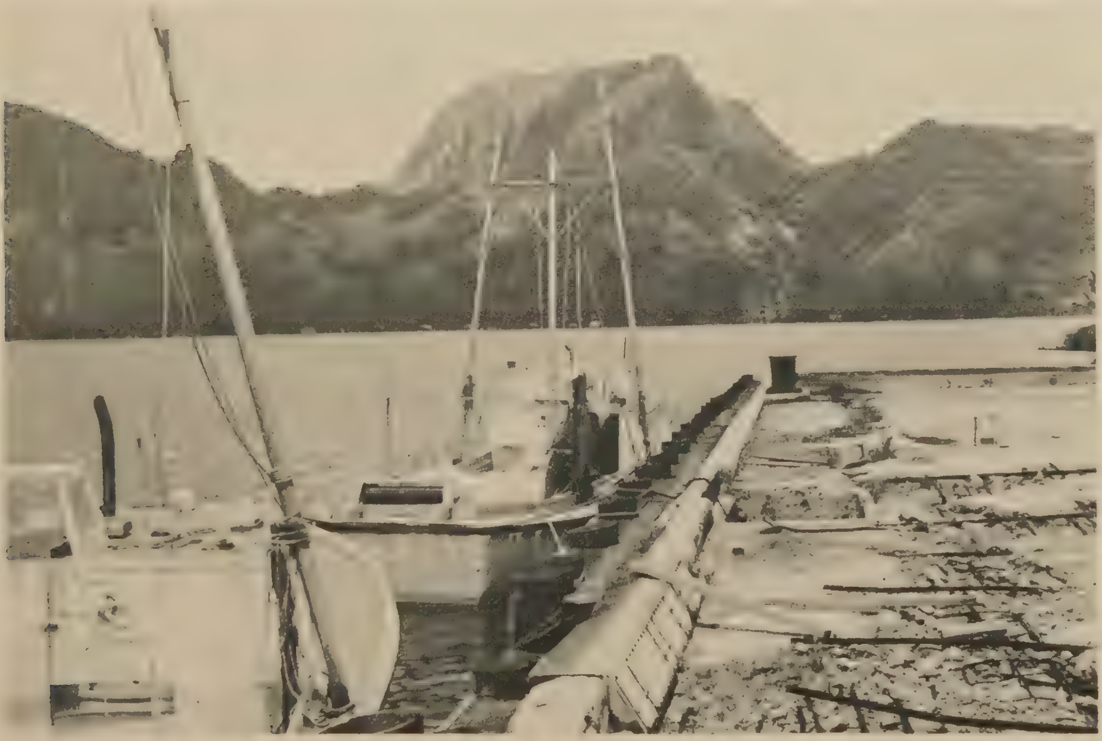

Fig. 4 - Salmon gill-net boats at the Oil Dock, Pago Pago Bay, rigged for tuna fishing with trolling outriggers and with long lines reeled up on the net drums.

CANNERY

The cannery is located at Atu'u, across Pago Pago Bay from the largest town and seat of the Government of American Samoa. It is a well-equipped modern plant, with two packing lines and a capacity estimated at between 20 and 25 tons of tuna or 1,000 cases of the finished product per day. The largest amount of tuna sent to the plant on any one day during this operation was about 16 tons, and the average day's run was 7 to 8 tons. Almost all of the tuna sent to the cannery was yellowfin over 120 pounds, which was packed as chunk style, unless it was of darker color, in which case it was grated. Small experimental lots of other styles were packed, and in the last 3 days of operation considerable quantities of albacore were received and put up as fancy solid pack (table 6).

Table 6 - Fish Received by the Cannery by Months

Species	February	March	April	Totals
	. . . .	. (Pounds) . .	. . . .	. . . .
Yellowfin, gutted	156,711	108,621	38,535	303,867
Yellowfin, round	42,599	-	-	42,599
Albacore, round	274	-	29,821	30,095
Big-eyed, gutted	2,483	1,639	1,605	5,727
Skipjack, round	365	40	-	405
Totals	202,432	110,300	69,961	382,693

The cannery has three Freon-refrigerated cold-storage rooms estimated to have a total tuna storage capacity of 60 tons. During this operation they were used for holding bait and provisions, and no tuna was stored in them. Construction of a flake-ice plant at the cannery was started in the middle of March and the plant was to go into operation in May. It has an ice-storage room of about 40 tons capacity insulated with aluminum foil and employs one belt icer operating off a $7\frac{1}{2}$" x $7\frac{1}{2}$" compressor and the flake-ice machine transferred from the North Star with two 6" x 6" compressors. Eventual installation of a 180-foot screw conveyor to carry the flake ice to the cannery pier is planned.

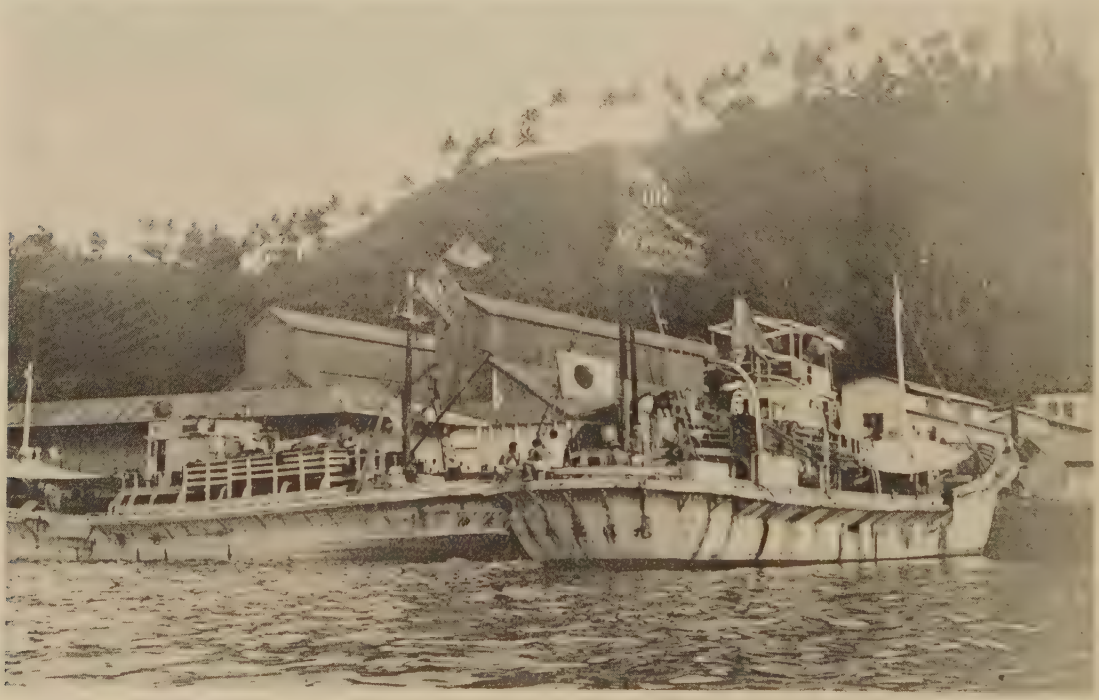

Fig. 5 - Japanese tuna boats at the Customs Pier in Pago Pago Bay, American Samoa, February 1954.

The cannery employed eight persons brought from the United States mainland in supervisory positions and about 160 local people, slightly more than half of them women occupied in cleaning and packing the cooked fish. Wage rates are in conformity with the scale used by the Government of American Samoa, which cooperates in the procurement of labor for the cannery. The Samoan workers were quick to learn their tasks and appeared reasonably efficient. In this connection it should also be noted that the agreement between the Samoan Government and the lessee provides that steps are to be taken to train Samoans in tuna fishing with a view to eventually using only local personnel in the production as well as in the processing end of the enterprise. No such training was undertaken during the period covered by this report.

Because of the large size of the long line-caught yellowfin, the cannery management anticipated considerable trouble with "green" and otherwise off-color fish. The actual occurrence of meat colors unsuitable for canning as bite-size light meat was as high as 20 to 30 percent in some batches of big tuna, but it was quite variable, being nearly absent from some batches, and the correlation between fish size and incidence of undesirable meat color was far from perfect. In general, the opinion of the operators seemed to be that the 20-percent discount on the price of fish over 120 pounds in weight was adequate to cover loss from this cause. Most of the fish rejected on this ground for chunk-style packing was satisfactory for canning as grated tuna, particularly if blended with a suitable proportion of lighter meat. Indications are that the amount of cooked fish rejected outright was small.

CONCLUSIONS

The first phase of the experiment in operating the Samoan cannery with tuna from Japanese fishing boats demonstrated that (1) yellowfin tuna and albacore can be taken by long lines in the vicinity of Samoa, and (2) Samoan cannery labor can produce an acceptable pack of canned tuna. The economics of cannery operation in Samoa have not yet become clear. They no doubt depend on the apparent advantages of price and labor costs coupled with ready access to fishing areas around many island groups, from the yellowfin grounds along the equator to the possibly important albacore grounds below 20° S. latitude, as balanced against the logistical difficulties of working in this isolated, distant part of United States' Pacific territories.

The experiment is continuing. Reports from Samoa are that two more Japanese long liners began fishing out of Pago Pago in May, and another two in June. The operations of these vessels were reported to be going much more smoothly than those of the earlier, larger fleet. The fishing grounds continued for the most part to be within 50 miles of the main Samoan islands, and catches were at the level of 2 tons per vessel per day, about one-fourth of which was albacore.